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Road vehicles — Transport information and control systems — Detection-response task (DRT) for assessing attentional effects of cognitive load in driving

Véhicules routiers — Systèmes d'Information et de commande du transport — Tâche de Détection-Réponse (DRT) pour l'évaluation des effets attentionnels de la charge cognitive lors de la conduite

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

The committee responsible for this document is ISO/TC 22, *Road vehicles*, Subcommittee SC 39, *Ergonomics*.

Introduction

Driving is a complex task consisting of a range of sub-tasks such as keeping the vehicle in the lane, avoiding other traffic and obstacles, observing road signs and signals, planning and initiating specific manoeuvres, scanning mirrors and navigating. In addition, drivers often engage in secondary tasks, not directly related to driving, such as operating the media player, conversing on the phone and reading road-side commercial signs.

These different activities place varying, and sometimes conflicting, demands on the driver. In order to manage the various driving and secondary tasks, the driver thus needs to allocate different *resources*, such as the eyes, hands, feet, perceptual systems, motor control systems and higher level cognitive functions, to the different sub-tasks in a dynamic and flexible way. This allocation of resources to driving and non-driving activities may be generally conceptualized as *driver attention*. In most driving situations, attention is determined by an interaction of proactive (top-down, endogenous) processes based on anticipation of how the upcoming situation will develop and bottom-up processes (driven by exogenous stimuli) which can trigger attention to the situation when it does not develop as expected, even leading to a corrective action.

There is a need for methods that can be used to assess how engagement in secondary tasks affects driver attention. In general, the effect of a task on attention depends on the amount and type of resources demanded by the task. As outlined in further detail in Annex A, resources can be conceptualized at three general levels: *sensory-actuator resources*, *perceptual-motor resources* and *cognitive resources*. *Sensory/actuator resources* refer to the basic interfaces between the driver and the environment used to sense the environment and perform overt actions. Examples include the eyes, the ears, the skin, the feet, the hands, the mouth, the vocal cords, etc. *Perceptual/motor resources* can be regarded as brain functions for controlling specific perceptual-motor activities, e.g. visual perception, manual tracking and hand-to-eye coordination. Finally, *cognitive resources* refer to brain systems implementing higher-level cognitive operations such as planning, decision making, error detection, sustaining information in working memory, dealing with novel or difficult situations and overcoming habitual actions. These types of high-level cognitive functions may be conceptualized in terms of *cognitive control*. While sensory-actuator and perceptual-motor resources are, at least to some extent, modality-specific, cognitive control can be regarded as a single resource with strongly limited capacity, not associated with any particular sensory modality. *Cognitive load* thus refers specifically to the demand for cognitive control that a task imposes on the driver.

Several existing and draft ISO standards address the assessment of secondary task demand in the context of driving. ISO 15007-1[1] and ISO/TS 15007-2[2] provide guidance on how to measure glance behaviour and ISO 16673[3] focuses exclusively on the viewing time required to perform a task using an in-vehicle information system. Hence, these methods focus mainly on the assessment of (visual) sensory demand (i.e. the demand for the eyes). ISO 26022[4] provides a technique for evaluating the combined effect of sensory-actuator, perceptual-motor and cognitive demands on a driver's performance in a combined event detection and vehicle control task.

However, a standardized measurement method that specifically addresses cognitive load is lacking. While, for example, ISO 26022 is sensitive to cognitive load, it lacks specificity since its main performance metric (MDEV) is also sensitive to visual sensory motor interference (i.e. visual time sharing; see Annex A). A standardized method specifically addressing cognitive load is particularly needed in order to evaluate the attentional demands of new driver-vehicle interfaces designed to minimize visual interaction such as voice-based interfaces, haptic input devices and head-up displays.

The detection-response task (DRT) method defined in this document intends to fill this gap. More specifically, the DRT is mainly intended to measure effects of the cognitive load of a secondary task on attention. However, some versions of the DRT specified in this document may also be used to capture other forms of secondary task demand (e.g. visual sensory demand). The general rationale behind the DRT methodology is further outlined in Annex A.

Annex B provides guidance on how to select among the different DRT versions defined in this document. Annex C reviews factors that could potentially affect DRT performance and thus need to be accounted for when designing DRT experiments. Annex D offers a review of existing alternative DRT methodologies not covered by this document. Annex E provides an overview of the results from a set of coordinated studies with the purpose to support the development of this document. Finally, a general bibliography is provided for existing DRT-related research.

Road vehicles — Transport information and control systems — Detection-response task (DRT) for assessing attentional effects of cognitive load in driving

1 Scope

This document provides a detection-response task mainly intended for assessing the attentional effects of cognitive load on attention for secondary tasks involving interaction with visual-manual, voice-based or haptic interfaces. Although this document focuses on the assessment of attentional effects of cognitive load (see Annex A), other effects of secondary task load may be captured by specific versions of the DRT, as further outlined in Annex B. Secondary tasks are those that may be performed while driving but are not concerned with the momentary real-time control of the vehicle (such as operating the media player, conversing on the phone, reading road-side commercial signs and entering a destination on the navigation system).

NOTE According to this definition, secondary tasks can still be driving-related (such as in the case of destination entry).

This document does *not* apply to the measurement of primary (driving) task demands related to the momentary real-time control of the vehicle, such as maintaining lane position and headway or responding to forward collision warnings. However, this does not preclude that the DRT method, as specified in this document, may be adapted to measure such effects.

This document applies to both original equipment manufacturer (OEM) and after-market in-vehicle systems and to permanently installed, as well as portable, systems.

It is emphasized that, while the DRT methodology defined in this document is intended to measure the attentional effects of cognitive load, it does not imply a direct relationship between such effects and crash risk. For example, taking the eyes off the road for several seconds in order to watch a pedestrian may not be very cognitively loading but could still be expected to strongly increase crash risk.

Furthermore, interpret DRT results cautiously in terms of demands on a specific resource, such as cognitive load. Specifically, if the goal is to isolate the effect related to the cognitive load imposed by a secondary task on attention, avoid overlap with other resources required by the DRT (e.g. perceptual, motor, sensory or actuator resources). A particular concern derives from the fact that the DRT utilizes manual responses (button presses). Thus, for secondary tasks with very frequent manual inputs (on the order of one or more inputs per second), increased response times on the DRT may reflect this specific response conflict (which is due to the nature of the DRT) rather than the actual cognitive load demanded by the task when performed without the DRT (i.e. alone or during normal driving; see Annex E). Thus, for such response-intensive tasks, DRT results are interpreted with caution. This document defines three versions of the DRT and the choice of version depends critically on the purpose of the study and the conditions under which it is conducted (see Annexes A and B for further guidance on this topic).

This document specifically aims to specify the detection-response task and the associated measurement procedures. Thus, in order to be applicable to a wide range of experimental situations, this document does not define specific experimental protocols or methods for statistical analysis. However, some guidance, as well as examples of established practice in applying the DRT, can be found both in the main body of this document and in the annexes (in particular Annexes C and E).

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— IEC Electropedia: available at http://www.electropedia.org/

— ISO Online browsing platform: available at http://www.iso.org/obp

3.1
actuator demand
demand for *actuator resources* (3.2) imposed by a *task* (3.30)

3.2
actuator resources
human body systems used to execute overt motor actions

Note 1 to entry: Examples of actuator resources include the hands, the feet, the vocal cords, etc.

3.3
attention
allocation of resources, encompassing both bottom up and top down attentional processes, to a particular activity or activities

3.4
cognitive control
mental operations such as planning, decision making, error detection, inhibiting habitual actions, utilizing information in *working memory* (3.36), and resolving novel and complex situations

3.5
cognitive resources
brain systems implementing *cognitive control* (3.4)

3.6
cognitive load
cognitive demand
demand for *cognitive control* (3.4) imposed by a *task* (3.30)

3.7
data segment
continuous portion of data

3.8
driver attention
allocation of *resources* (3.20), encompassing both bottom up and top down attentional processes, to driving and/or non-driving-related activities

3.9
DRT stimulus
sensory signal controlled and issued to a participant during a DRT test session for the purpose of eliciting a specified *response* (3.21)

3.10
hit
response (3.21) initiated within 100 ms to 2 500 ms from the *stimulus onset* (3.29), not preceded by an earlier response in the same interval

Note 1 to entry: Hit is synonymous with valid response.

3.11
hit rate
number of *valid responses* (3.33) divided by the total number of stimuli presented in a data collection segment, excluding premature responses to stimuli

Note 1 to entry: See *premature response* (3.17).

3.12
missing response
absence of a *response* (3.21) within 100 ms to 2 500 ms after *stimulus onset* (3.29)

3.13
motor demand
demand for *motor resources* (3.13) imposed by a *task* (3.30)

3.14
motor resources
brain systems implementing the control of motor actions

3.15
perceptual demand
demand on *perceptual resources* (3.15) imposed by a *task* (3.30)

3.16
perceptual resources
brain systems implementing perception

Note 1 to entry: Perceptual functions include lower-level, modality-specific perception (e.g. visual and auditory perception), as well as higher-level cross-modal perceptual integration.

3.17
premature response
response (3.21) initiated within 100 ms from the *stimulus onset* (3.29), prior to the timing interval for a *valid response* (3.33)

3.18
primary task
driving or driving-like *task* (3.30) used in the surrogate driving, driving simulator or on-road DRT experimental setups

3.19
repeated response
response (3.21) initiated within 100 ms to 2 500 ms after the *stimulus onset* (3.29) that is preceded by an earlier response in the same interval

3.20
resources
systems in the brain or body that can be utilized to perform *tasks* (3.30)

3.21
response
signal generated by the participant pressing the response button

3.22
response time
time from the *stimulus onset* (3.29) until the response onset

Note 1 to entry: Response time is only defined for valid responses.

3.23
secondary task
task (3.30) that may be performed while driving but that is not concerned with the momentary real-time control of the vehicle

Note 1 to entry: Examples include operating the media player, conversing on the phone, reading road-side commercial signs and entering a destination on the navigation system. Thus, secondary tasks may be driving-related.

3.24
sensory demand
demand on *sensory resources* (3.24) imposed by a *task* (3.30)

3.25
sensory resources
human body systems used to sense the exterior environment or internal bodily states

Note 1 to entry: Examples of sensory resources include the eyes, the ears, the skin, etc.

3.26
stimulus duration
time during which the stimulus is turned on

Note 1 to entry: The maximum stimulus duration is set at 1 s.

Note 2 to entry: Stimulus duration depends on responses. The maximum stimulus duration represents the pre-set duration of the stimulus in the absence of a response. If the response is initiated prior to maximum stimulus duration, the stimulus is turned off.

3.27
stimulus cycle period
time from the onset of a stimulus until the onset of the next stimulus

3.28
stimulus offset
point in time when the *DRT stimulus* (3.9) is turned off

3.29
stimulus onset
point in time when the *DRT stimulus* (3.9) is turned on

3.30
task
process of achieving a specific and measurable goal using a prescribed method

3.31
trial
test of one participant undertaking one *secondary task* (3.23) one time

3.32
unrequested response
response (3.21) given later than 2 500 ms after the *stimulus onset* (3.29)

3.33
valid response
response (3.21) initiated within 100 ms to 2 500 ms from the *stimulus onset* (3.29), not preceded by an earlier response in the same interval

Note 1 to entry: Valid response is synonymous with *hit*.

3.34
visual angle
angle subtended at the eye by a viewed object or separation between viewed objects

Note 1 to entry: Measurement of visual angle is made edge to edge.

3.35
visual eccentricity
visual angle (3.34), relative to the centre of the fovea, at which a certain visual stimulus impinges on the retina

Note 1 to entry: Measurement of visual eccentricity is made from centre of eye to centre of visual stimulus.

3.36
working memory
executive and attentional aspect of short-term memory involved in the interim integration, processing, disposal and retrieval of information

4 Abbreviated terms

ANOVA	analysis of variance
B	baseline
DRT	detection-response task
HDRT	head-mounted DRT
HR	hit rate
MR	miss rate
N0	0-Back
N1	1-Back
OEM	original equipment manufacturer
R	response
RT	response time
RDRT	remote DRT
SE	easy SuRT
SH	hard SuRT
TDRT	tactile DRT

5 DRT methodology: Principles and overview

The DRT method is based on a simple detection-response task where participants respond to relatively frequent artificial stimuli presented with a specified degree of temporal uncertainty. Detection performance, measured in terms of response time and hit rate, is assumed to represent the degree to which attention is affected by the demand and, in particular, the cognitive load component imposed by the secondary task under evaluation. Longer reaction times and reduced hit rate are indicative of higher cognitive load.

The method may be implemented in several different ways, depending on the purpose of the study. The DRT versions specified by this document differ in terms of stimulus presentation modality and experimental setup, as further described below.

6 Measurement methods and procedures

6.1 Participants

Participants should be licensed drivers with a similar level of prior experience with the secondary task under evaluation. Other relevant characteristics of the participants shall be recorded, including at least driving experience (e.g. miles or km driven in the last year), similar device use experience, gender, age and previous experience with the DRT.

6.2 Experimental setup

The DRT may be used in different experimental setups as described below.

6.2.1 Non-driving experimental setup

In this setup, the DRT is performed concurrently with the secondary task under evaluation in a non-driving situation. This means that attention is divided between the secondary task under evaluation and the DRT, without simultaneous performance of a primary (driving or driving-like) task. DRT performance with the secondary task is assessed relative to a baseline condition where only the DRT is performed. The non-driving version of the DRT may be used to assess how a secondary task affects selective attention in any non-driving setting, including production vehicles, vehicle mock-ups or at a desktop.

6.2.2 Surrogate driving experimental setup

In this setup, the DRT is performed concurrently with the secondary task under evaluation while the participant performs a surrogate task that functions as the primary task of driving. This surrogate task could be a simple tracking task, watching a video of real-world driving recorded from the driver's viewpoint or a combination of such elements. DRT performance during the combined secondary task and surrogate driving is assessed relative to a baseline condition where the DRT is performed with only the surrogate driving task.

6.2.3 Driving simulator experimental setup

In this setup, the DRT is performed concurrently with the secondary task under evaluation while the participant drives a driving simulator. DRT performance during the combined secondary task and simulator driving is assessed relative to a baseline condition where the DRT is performed while only driving the simulator. The same scenario is used in both conditions.

6.2.4 On-road experimental setup

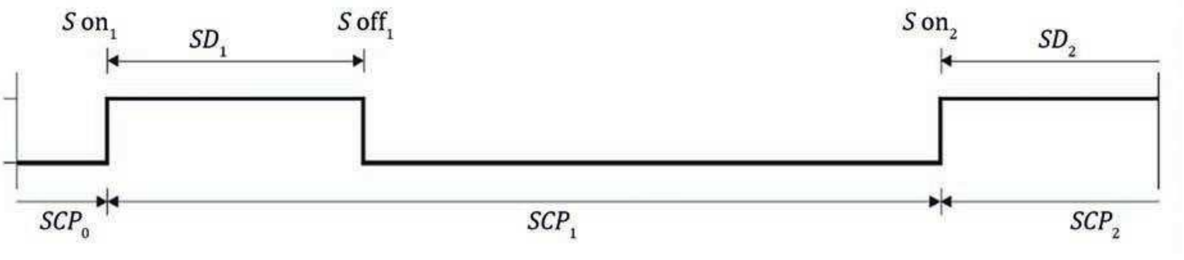
In this setup, the DRT is performed concurrently with the secondary task under evaluation while the participant drives on a closed track or an open road with traffic. Appropriate safety concerns shall be addressed for on-road testing. DRT performance during the combined secondary task and driving is assessed relative to a baseline condition where the DRT is performed while only driving.

6.3 Stimulus presentation

This document specifies three alternative methods for presenting the DRT stimulus. This includes two methods where the stimulus is presented visually and one method where the stimulus is provided by means of tactile stimulation. In the head-mounted DRT (HDRT), a visual stimulus (an LED) is presented through a fixture attached to the head of the participant at a specified visual angle. In the remote DRT (RDRT), a visual stimulus (e.g. an LED or embedded graphic in simulator scenario) is presented in the forward view of the participant. Finally, in the tactile DRT (TDRT), a tactile vibrator is placed on the participant's body. These stimulus presentation methods are described in further detail below. Guidelines for the selection of stimulus presentation mode depend on the purpose of the experiment and are provided in Annex B.

6.3.1 Stimulus presentation timing

The stimulus presentation timing is the same for all three stimulus presentation methods. Figures 1 and 2 illustrate the key principles. The stimulus onset (S_{on}) represents when the stimulus is turned on and the stimulus offset (S_{off}) when it is turned off. The *stimulus duration* (*SD*) represents the time during which the stimulus is turned on and the *maximum stimulus duration* (SD_{max}) represents the pre-set maximum duration of the stimulus. SD_{max} should be set to 1 s. The *stimulus cycle period* (*SCP*) represents the time from the onset of one stimulus until the onset of the next stimulus. The stimulus cycle period shall vary and be drawn randomly from a uniform distribution of values between 3 s and 5 s.



Key

S_{on}	stimulus onset
S_{off}	stimulus offset
SD	stimulus duration
SCP	stimulus cycle period

Figure 1 — Definition of parameters relevant for stimulus presentation specification

A signal generated by the participant pressing the response button is referred to as a response (R). If the participant responds while the stimulus is turned on, the stimulus is turned off at the moment of response (see Figure 2).

Key

S_{on}	stimulus onset
S_{off}	stimulus offset
SD	stimulus duration
SD_{max}	maximum stimulus duration
R	response

Figure 2 — Illustration of how the stimulus duration is determined by the response (R)

6.3.2 Visual stimulus specifications

6.3.2.1 Head-mounted visual stimulus

In the head-mounted DRT, the visual stimulus shall be presented by means of a single LED presented on a stalk attached to the participant's head. Compared with the remote DRT, the head-mounted DRT has the main advantage that it is not affected by drivers' head motion or if drivers look away from the forward view. Figure 3 shows the setup for the head-mounted DRT. The LED should be supported by a black frame as shown in Figure 3 and should be positioned to the left if the vehicle has the steering wheel to the left and to the right for vehicles with the steering wheel to the right. For a non-driving experimental setup, the LED should be placed either to the left or right, but in a way that visual interference with the secondary task is minimized. More precisely, the LED should be positioned 20° to the left or right (depending on steering wheel position) along the horizontal meridian and 10° above the vertical meridian, using the left or right eye as reference point, as illustrated in Figure 3. The distance between the eye closest to the LED and the LED should be 12 cm to 13 cm. The position of the LED should be verified on a human or manikin head prior to beginning the experimental trials. However, it does not have to be measured individually for each subject. Recommended default specifications for the LED are given in Table 1. The luminous intensity of the LED should be adjusted to the lighting conditions in the experimental setup so that the visual stimulus is easily detectable while not inducing discomfort or harm to the participant.

Table 1 — Recommended specifications for the LED for the head-mounted DRT

Parameter	Value
Colour	Red
Dominant wavelength	626 nm
LED response time	90 ns
Diameter	5 mm
Maximum luminous intensity	0,055 cd

Care should be taken to ensure that no portion of the LED is in the blind spot of the left eye. This can be ensured by covering the right eye (when the LED is positioned to the left) and asking the test subject to fixate straight ahead with the left eye. The entire LED (when continuously on) should then be clearly visible in the peripheral visual field of the left eye (when the LED is positioned to the right, the reverse applies).

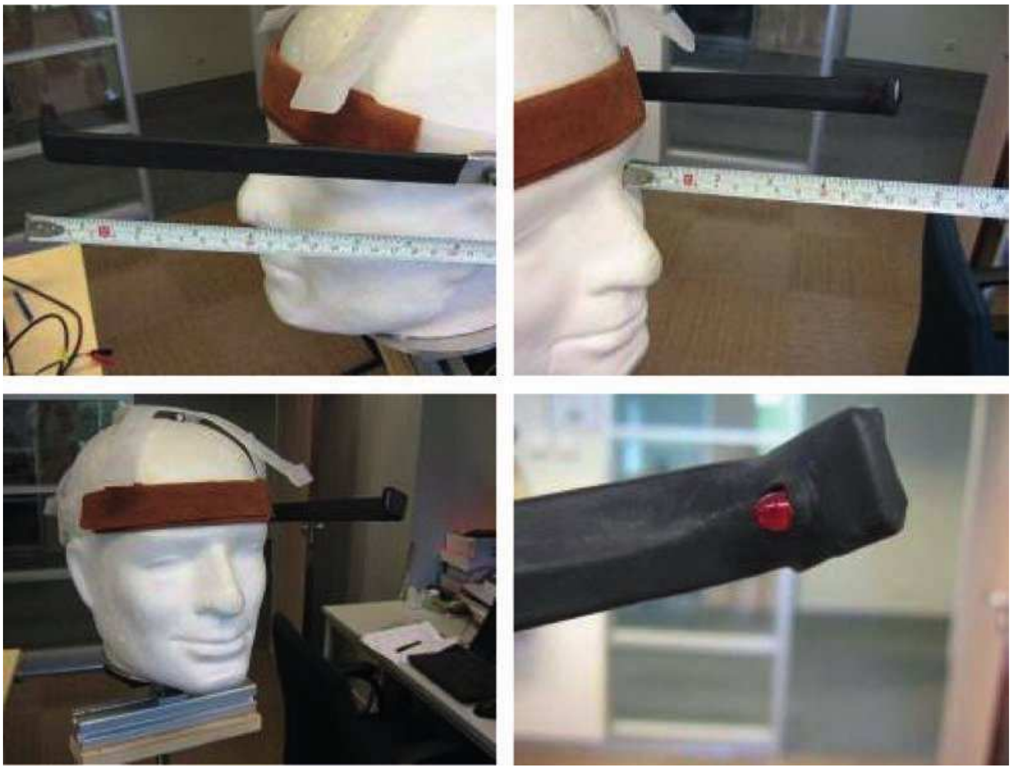


Figure 3 — Illustration of the setup for the head-mounted DRT

6.3.2.2 Remote visual stimulus

The stimulus for the remote DRT can be implemented as a single LED or, in driving simulator setups, as a graphical object displayed in a fixed location in the visual display. If an LED is used to generate the stimuli, it should be placed remotely from the participant, and should be clearly perceptible when gaze is directed straight towards the forward roadway. The LED should be directly perceived by the driver (i.e. not only indirectly perceived, for example, through reflection in the windshield). The exact positioning of the LED depends on the experimental setup. For example, in a passenger vehicle or simulator mock-up, the top of the dashboard would be a suitable position for the LED, as long as it is not occluded by the steering wheel. In outdoor conditions, care should be taken to find a position where the influence of ambient lighting on stimulus visibility is minimized (e.g. by means of shielding).

Recommended default specifications for the LED are given in Table 2. The luminous intensity of the LED should be adjusted to the lighting conditions in the experimental setup so that the visual stimulus is easily detectable while not inducing discomfort or visual impairment to the participant.

Table 2 — Recommended specifications for the LED for the remote DRT

Parameter	Value
Colour	Red
Dominant wavelength	626 nm
LED response time	90 ns
Diameter	5 mm (placed at a distance that subtends approximately 1°)
Image luminance	2 cd/m2

The exact position of the RDRT stimulus (distance from the participant, visual angle, etc.) shall be reported in each experiment. If the stimulus is presented graphically on a visual display, the stimulus should be implemented as a red filled circle, subtending a visual angle of about 1°. The stimulus should be presented within the driver's central field of view in a fixed location on the screen.

6.3.2.3 Tactile stimulus specification

A small electrical vibrator (tactor) is used to present the stimulus for the tactile DRT. The tactor should be placed on the driver's left shoulder if the vehicle has the steering wheel on the left and the opposite shoulder for vehicles with the steering wheel on the right. For a non-driving experimental setup, the tactor can be placed on either side. The tactor may be attached using medical tape, as illustrated in Figure 4. The intensity of the tactor should be such that it is easily detectable while not inducing discomfort to the participant. This should also include consideration for vibrations in the test environment such as vehicle vibration for on-road setup. Caution should be taken to avoid interference with the seat belt when it is fastened. The technical specifications of the tactor should be documented since the characteristics of the tactor (type, frequency and acceleration) may influence reaction time.

Recommended default specifications for the tactor are given in Table 3.

Table 3 — Recommended specifications for the tactor

Parameter	Value
Diameter	10 mm
Weight	1,2 g
Maximum speed	12 000 rpm
Vibration amplitude	0,8 G

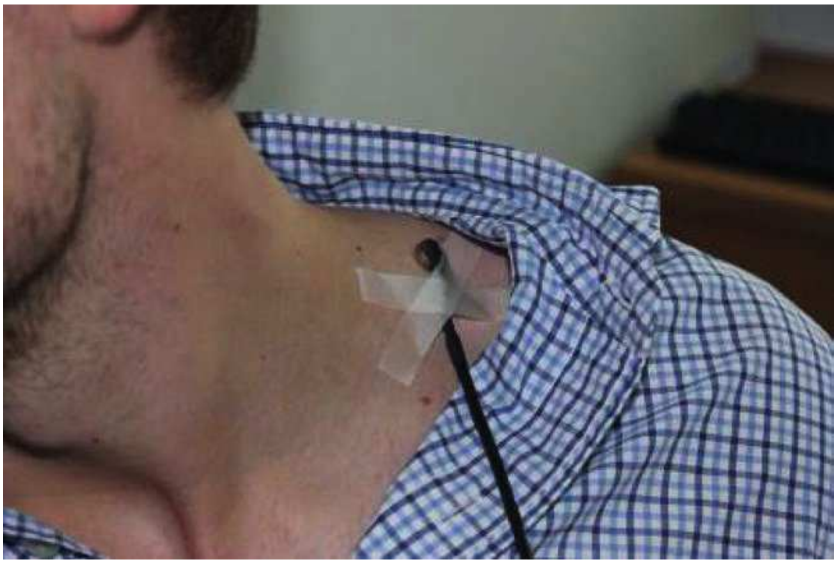


Figure 4 — Placement and attachment of the tactor

6.4 Response method

For all versions of the DRT, participants respond by pressing a micro-switch. It can be attached to the index finger, the middle finger or the thumb, as chosen by the participant, but placement should remain consistent throughout testing. The micro-switch should be attached to the participant's left hand if the vehicle has the steering wheel on the left and to their right hand for vehicles with the steering wheel on the right. An example is illustrated in Figure 5.

The micro-switch should generate a binary signal representing the response signal in Figure 2. In experimental setups involving driving, or a surrogate for driving involving the use of the steering wheel, the response should be made by pressing the switch to the steering wheel. In non-driving experimental setups, the micro-switch should be pressed against the thumb or the desktop (as chosen by the participant). The micro-switch shall provide perceptible feedback clearly indicating that a response has been made.

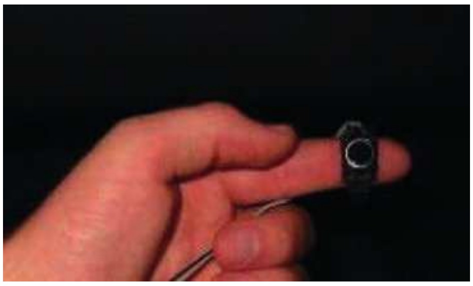


Figure 5 — Illustration of the setup for the response micro-switch

6.5 Primary driving task

If the DRT is used in a surrogate driving, driving simulator or on-road experimental setup, the nature of the primary task shall be clearly reported. Factors that should be considered are provided in Annex C.

6.6 Instructions to participants

At a minimum, the following instructions should be given to participants before training on the different tasks.

a) Welcome the participant and give a brief overview of the purpose of the test, its expected duration and the test procedure.

b) Emphasize that the intention is not to test participant skills but rather how different tasks might affect performance.

c) Explain the secondary task to be evaluated, the general principles behind the DRT and the primary task (if applied in a surrogate driving, driving simulator or on-road experimental setup). The participant should be instructed to prioritize the primary task (driving or a surrogate for driving) and then, as a lower priority, do their best to also perform both the secondary task under evaluation and the DRT. In the non-driving experimental setup, the participant should be instructed to do their best to perform both the secondary task under evaluation and the DRT simultaneously. The following is an example of a task priority instruction suitable for an experimental setup involving driving: “Your main priority is to drive safely. Please remember to maintain your position within your given travel lane. The [LED/tactor] and the [secondary task] task will both be active during the run. Please do your best to pay attention to both tasks but recall that your primary task is safe driving.”

d) Explain to the participant that the data collection and analysis programmes are designed to ignore participant responses that are given when there is no stimulus presented. Thus, a strategy of performing continuous button pressing regardless of stimulus presentation will not yield better performance and shall lead the participant to be excluded from the experiment.

6.7 Training procedure

Prior to the experimental tests, the participant shall be separately trained on the following tasks in the following order:

a) the secondary task(s) under evaluation;

b) the DRT;

c) if a surrogate driving, driving simulator or on-road experimental setup is used, the primary (driving or driving-like) task.

Finally, the two or three tasks should be practiced together. The detailed training procedure is specified in the following sections.

6.7.1 Secondary task training

Training on the secondary tasks shall initially be performed under single task conditions. A demonstration of the task shall first be given to the participant by the experimenter. Participants shall then be given a sufficient number of practice trials for each secondary task being investigated until they reach stable performance and feel comfortable that they can perform the task successfully. If three out of the first four participants cannot successfully complete the practice task at least once in five trials, the interface design and training protocol should be reviewed.

The number of practice trials shall be recorded for each participant and task for post-test analysis. Information to be viewed or entered for a secondary task in practice trials should be different from those used in test trials but equal in complexity (e.g. street name length in a destination entry task).

Each practice task should be completed using the designated method and the experimenter should aim to ensure the appropriate completion of the task by coaching or assisting if the participant is having difficulty with the task. Care should be taken to ensure that the participant understands the instructions.

6.7.2 DRT training

When the secondary task training is completed, the participant shall be trained on performing the DRT (without performing the secondary or driving tasks). The training shall continue until the subject responds to the stimuli in a stable manner (as judged by the experimenter) and reports feeling comfortable with performing the task. The experimenter is advised to observe the participant during the entire training phase to ensure that the participant attempts to respond as quickly as possible to the DRT stimulus. If admonishing a subject who is not responding as quickly as he/she could do fails to modify their behaviour accordingly, the subject should be eliminated from the test programme. In addition, the experimenter should check that the participant does not simply press the button repeatedly without consideration of the stimuli.

6.7.3 Primary task training

If the surrogate driving, driving simulator or on-road experimental setup is used, the participants shall also be trained on the primary task (without performing the secondary task or the DRT). Training on the primary task should continue until stable performance is achieved and the participant feels comfortable with the task. Test participants who are apparently incapable of mastering the primary task, or who complain of motion sickness during training, should be eliminated from the test programme.

6.7.4 Training on multitasking

Finally, the participants shall be trained on performing the secondary tasks together with the DRT and the surrogate driving, driving simulator or on-road experimental setup, if used. In studies where several secondary tasks are to be evaluated, the multitasking condition shall be practiced for each. The training shall continue until stable multitasking performance is achieved and the participant reports feeling comfortable with performing the two or three tasks simultaneously. Participants who are clearly incapable of mastering the multitasking should be eliminated from the test, and this number shall be documented along with the reasons for their exclusion.

6.8 Performance measures

Two performance measures shall be calculated: hit rate and response time. A hit is defined as a *valid response* to a DRT stimulus. A valid response is defined as a response initiated within 100 ms to

2 500 ms from the stimulus onset, and which is not preceded by an earlier response in the same interval. Responses can be categorized as valid or invalid. There are three general types of invalid responses, all of which shall be excluded from the calculation of hit rate.

a) *Premature responses*: Responses initiated within 100 ms from stimulus onset, prior to the timing interval for a valid response. The purpose of this criterion is to exclude unrealistically fast responses.

b) *Unrequested responses*: Responses initiated later than 2 500 ms after stimulus onset.

c) *Repeated responses*: Responses initiated within the 100 ms to 2 500 ms after the stimulus onset that is preceded by an earlier response in the same interval.

A response is considered *missing when* no response is given within 100 ms to 2 500 ms from stimulus onset.

The *hit rate* (HR) is defined as the number of hits (valid responses) divided by the total number of stimuli presented during a data segment. In some applications, it may be desired to report miss rate rather than hit rate. A miss is simply defined as the complement of a hit. Hence, the *miss rate* (MR) is defined as the hit rate subtracted from 1.

The *response time* (RT) is calculated for hits only and is defined as the time from stimulus onset until the response. The RT value for an individual participant for a given task or baseline segment is calculated as the mean response time to all valid responses (hits) during that segment.

The number of stimuli shall be sufficient to provide enough response times for statistical analysis. A data segment shall exceed a duration of 5 s to qualify for analysis, which guarantees that it will include at least one stimulus. In addition, at least five stimuli should be included in the analysis of each task. This could be accomplished either by collecting multiple short data segments for the same task or by repeating the task within a single data segment until at least five stimuli have been presented.

6.9 Analysing and interpreting DRT performance data

RT and hit rate are both important and should be considered in the interpretation of the results from DRT studies. However, there are some important issues that should be considered when analysing DRT data. First, hit rates are generally not normally distributed (see Figure E.6). One reason for this is that there is often a strong ceiling effect, especially in baseline data, where most data points take the value of 1 (i.e. 100 % hit rate). Moreover, for short data segments, the hit rate can take only a limited number of discrete values. For example, for a data segment that contains only five DRT stimuli, the hit rate can take only the values of 0, 0,2, 0,4, 0,6, 0,8 and 1. In such cases, the assumptions of parametric statistical tests (e.g. *t*-tests and ANOVAs) may be violated and it is recommended that non-parametric statistical tests are used instead. Caution should be taken to avoid comparing tasks of short and long durations.

Moreover, difficulties interpreting the data may arise if the two performance measures (hit rate and response time) do not consistently indicate an effect in the same direction. An example would be when the secondary task under evaluation leads to strong reduction in hit rate but no effect on response time. In such cases, the DRT response time should be interpreted with caution.

6.10 Checking data quality

The following steps shall be taken to ensure sufficient data quality.

To check data quality, the frequency distribution of response times across participants should be plotted in the form of a histogram. If the collected data deviates substantially from the positively skewed reference distribution given in Figure 6, the DRT measurement setup should be checked for possible technical problems. To avoid losing test data, this check should be performed during pilot testing.

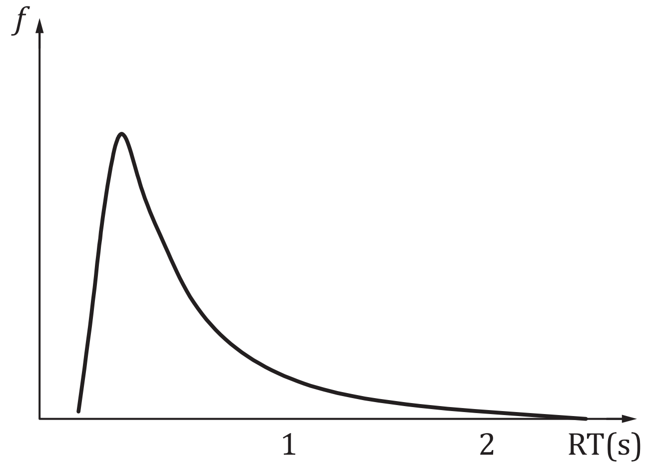


Figure 6 — Reference RT distribution for checking DRT data quality

The data shall also be checked for cheating strategies. It is possible for participants to attempt to increase their hit rate by repeatedly pressing the response button regardless of stimulus presentation. To reveal such strategies, the total number of responses for a participant should be divided by the total number of stimuli for that same participant in a given data collection segment. If this ratio exceeds 2, the participant should be excluded from the analysis. Video recording and monitoring are useful methods to determine if cheating strategies are being used by participants.

6.11 Use of DRT data in decision making

The detection-response task (DRT) procedures set out in this document provide methods to assess the effects of cognitive load, resulting from performance of a secondary task, on attention. Three implementations of the DRT methodology are presented, the head-mounted, the remote and the tactile versions. In addition, four different experimental setups are described (i.e. non-driving, surrogate, driving simulator and on-road setups). While these different DRT methods are robust in detecting differences in cognitive load, the absolute values of the measures were found to vary across testing locations as might be expected due to different setups and laboratory conditions. Consequently, meaningful assessments of performance should be conducted by a comparison of relative performance rather than by comparison to an absolute value. This can be accomplished by comparing, for example, reaction time performance in the conditions of interest (i.e. with secondary tasks) with reaction times for baseline performance.

Annex A
(normative)

Rationale

A.1 General

As stated in the introduction of this document, the main goal of the DRT methodology is to measure *the effects of cognitive load on driver attention.* This annex provides a rationale for this statement by outlining conceptual framework for understanding driver attention and its relation to cognitive load. This account is not based on a specific theory of attention or cognitive load but rather seeks to incorporate ideas from several contemporary theories into a generic framework.

A.2 Driver attention

Driver attention can be generally conceptualized as *the allocation of resources to a set of activities*.[30] This allocation of resources encompasses both bottom-up and top-down attentional processes. *Activities* performed by drivers could be goal-directed or not related to any particular goal. Goal-directed activities could be considered as *tasks*. Moreover, activities (and tasks) are more or less related to driving. Driving consists of multiple tasks that can be characterized as operational (e.g. basic vehicle control), tactical (e.g. decisions on which manoeuvre to initiate) or strategic (e.g. route choice and navigating[66]). Non-driving activities include the operation of secondary tasks such as radio tuning, cell phone dialling, conversation with passengers or performance of the DRT. It is sometimes difficult to draw a distinct line between driving and non-driving tasks; however, such a sharp distinction is not needed for present purposes.

Attention is generally characterized by activation and selectivity. *Activation* refers to the degree to which resources are allocated to an activity, that is, *how much* attention is allocated.1) By contrast, *selectivity* refers to how resources are distributed between activities. If there are multiple activities with competing resource demands, the driver shall prioritize certain activities above other activities. *Selecting* an activity at a particular moment in time can thus be understood as allocating sufficient resources to that activity.2) Attention is driven both *exogenously* (bottom-up, by factors external to the driver such as salient stimuli) and *endogenously* (top-down, by goals and expectancies of the driver[75]).

Resources that can be allocated to activities may be conceptualized at three levels: sensory/actuator resources, perceptual/motor resources and cognitive control.

Sensory/actuator resources refer to the basic interfaces between the driver and the environment used to sense the environment and perform overt actions. Examples include the eyes, ears, skin, feet, hands, mouth, vocal cords, etc.

Perceptual/motor resources can be regarded as brain systems for performing specific perceptual-motor activities. These resources can be characterized along multiple dimensions including perceptual and motor *modalities,* such as visual, auditory and tactile and *response codes*, such as spatial vs. verbal.[98][99] In general, tasks with overlapping perceptual/motor resources will interfere more than tasks demanding separate resources. However, as shown, for example in References [25] and [41], different forms of cross-modal interactions make it difficult to precisely define a finite set of independent perceptual/motor resources.

1) The concept of an activation level is closely related to the "alerting attention" system proposed by Posner (e.g. Reference [76]) which refers to achieving and maintaining an alert state. The activation level is partly, but not entirely, determined by the degree of mental effort[54] mobilized by the driver.

2) The concept of "selectivity" is related to the "orienting attention" system[76] defined as the selection of information from sensory input.

Finally, *cognitive resources* refers to brain systems implementing higher-level mental operations such as planning, decision making, error detection, inhibiting habitual actions, utilizing information in working memory and resolving novel and complex situations. These functions may be conceptualized in terms of *cognitive control*.3)[67] This intentional, top-down allocation of cognitive control generally requires mental effort and is accessible to conscious awareness. Moreover, cognitive control is not specific to any sensory/motor modality and can generally be regarded as a single resource with limited capacity. This is supported by neuroimaging studies demonstrating that a wide variety of cognitive tasks recruit essentially the same frontal brain regions (in particular the lateral prefrontal cortex and the anterior cingulate cortex; e.g. Reference [27]). Finally, demands on cognitive control are reduced with practice, leading to gradually increasingly automatized performance.[76][88] However, as pointed in Reference [38], whether any real-world driving tasks are completely automatized can be questioned. Rather than defining automatization as an all-or-none phenomenon, it seems more appropriate and useful to consider a continuum from controlled performance (relying strongly on cognitive control) to automatic performance (with no demand for cognitive control[17]). The proposed general resource model is illustrated in Figure A.1.

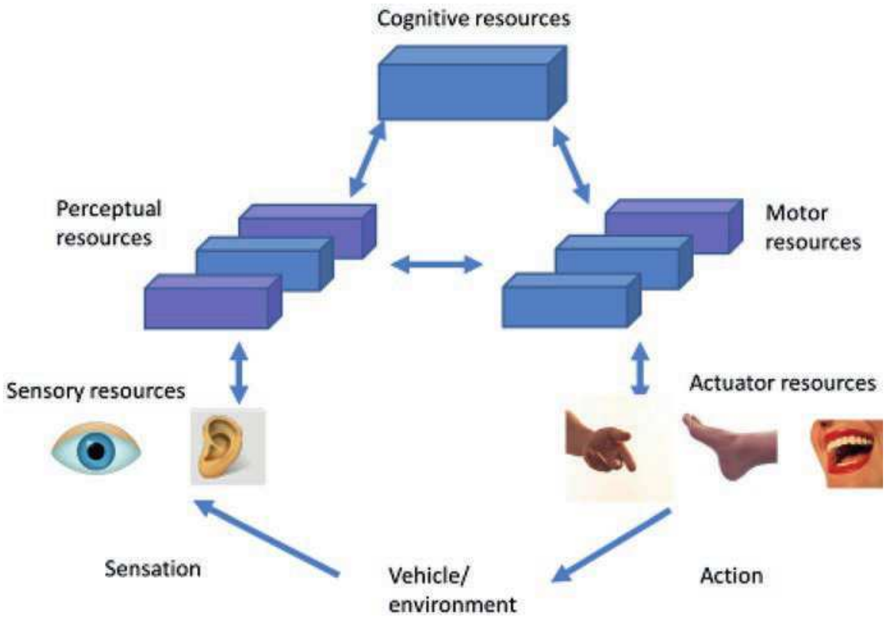


Figure A.1 — Illustration of the three-level resource model outlined in the text

A.3 Resource demands and task interference

Different activities place different demands on resources. Based on the three general resource levels outlined above, three corresponding types of demand may be distinguished.

— *Sensory/actuator load* refers to demands for sensory/actuator resources. Examples include demand for the eyes to monitor the road ahead or to view a display and demand for the hands to steer the vehicle or turn a knob on the radio.

— *Perceptual/motor load* refers to demands for perceptual/motor resources. Examples include demand for visual perceptual resources to detect a lead vehicle braking or to perceive the content of a display and manual motor resources to control braking or perform the radio knob turning action.

— *Cognitive load* refers to demands for cognitive resources (i.e. those resources needed for cognitive control). This involves the demand for executive functions and the associated mental effort needed to, for example, maintain items in working memory, deal with novel or inherently difficult tasks

3) There exists a variety of other terms for referring to these types of high-level cognitive functions, such as executive attention[76] and supervisory attention.[73] Here, these terms are treated as roughly equivalent to cognitive control.

or to overcome learned habits. Examples include the mental effort needed to negotiate a complex intersection or the working memory demands imposed by phone conversation. The cognitive load that a task imposes on a driver cannot be measured directly, but only in terms of its effects on attention, that is, how it affects the allocation of resources to activities. Thus, in this document, the main goal of the DRT methodology is stated in terms of measuring *the effect of cognitive load on driver attention* (rather than measuring cognitive load directly).

The allocation of resources to activities (i.e. attention) with different resource demands is further illustrated in Figures A.2 and A.3. Figure A.2 illustrates the hypothetical demands and resource allocation for lane keeping in normal, non-demanding, conditions (e.g. driving in clear weather on a sparsely trafficked motorway). As shown, lane keeping is assumed to demand the eyes, the hands, visual spatial perception and manual control, but, due to the high degree of automatization, very little cognitive resources.

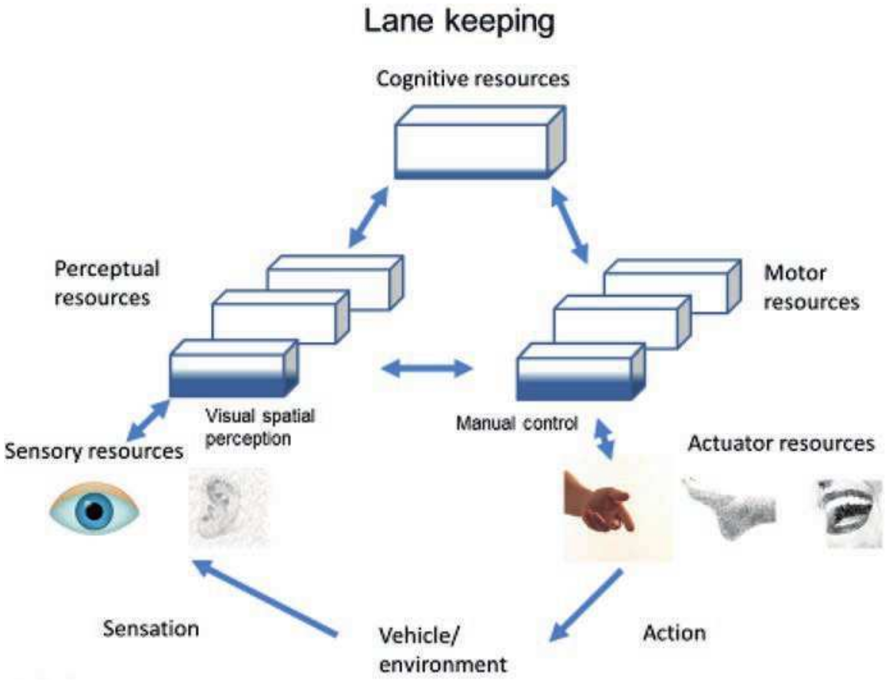


Figure A.2 — Hypothetical resource allocation for lane keeping in normal (non-demanding) driving conditions

Figure A.3 illustrates a corresponding hypothesized resource allocation for hands-free phone conversation. This task can be assumed to demand the ear(s), the speech motor system, auditory perception, speech control and a relatively large amount of cognitive resources (depending on the content of the conversation). Different activities may thus demand different resources, and resources may be allocated to different degrees (except for the sensory and actuator resources which can be thought of as allocated in a more all-or-none fashion – either the hand/eye is used or not).

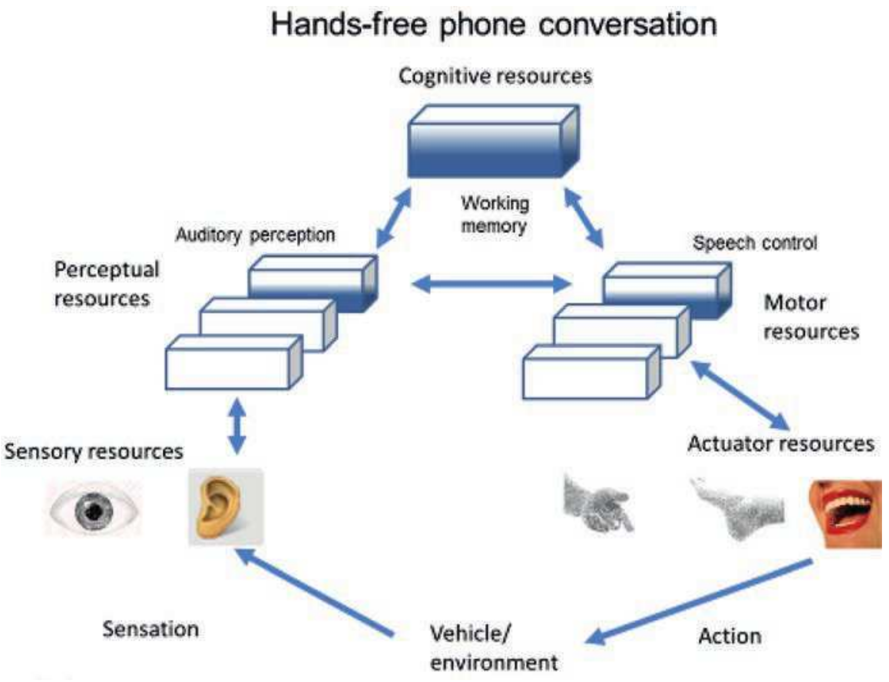


Figure A.3 — Hypothetical resource allocation for hands-free phone conversation

The *interference* between two activities or tasks is generally determined by the degree to which the tasks place overlapping demands on the resources needed to service them.[98][99] In the case of significant overlap, there may be an insufficient amount of resource(s) to support both tasks simultaneously at the time of demand. In such cases, performance on one or both tasks may suffer, depending on how the person prioritizes between the tasks. This situation is schematically illustrated in Figure A.4, where two tasks place overlapping demands on a specific resource and the total resources demanded for optimal performance on both tasks exceed the available resources. In this example, Task 1 is prioritized which leads to degraded performance on Task 2. Resource allocation strategies are further addressed in A.4.

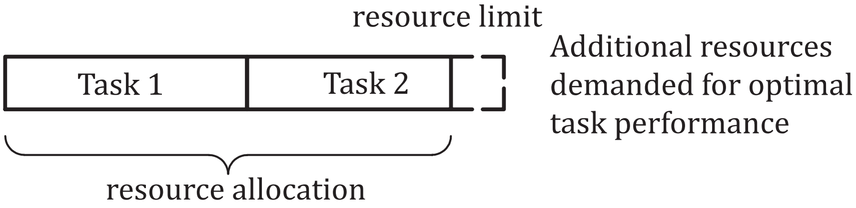


Figure A.4 — Illustration of total resource demands needed for satisfactory performance on two tasks exceed the available resource

However, based on a multiple resource model such as that outlined above, task interference may occur in parallel for the specific resources. *Sensory/actuator interference* results from concurrent demands for the same sensory/actuator resources when there is an insufficient amount of resources to support both tasks simultaneously at the time of demand. These concurrent demands may, for instance, occur due to a spatial separation between the forward road scene and a visual display (requiring the driver to look away from one visual location to view the other) or due to concurrent demands for the hands by the tasks of steering and peeling a banana. Sensory/actuator interference is fundamental in the sense that the interference is not reduced with practice (however, the ability to *deal with* sensory/actuator interference by scheduling, or time-sharing, attention back-and-forth between competing tasks, e.g. by shifting gaze, is a skill developed with practice).

Similarly, *perceptual/motor interference* arises from concurrent demands for the same perceptual/motor resources when there is an insufficient amount of resources available to support both tasks simultaneously at the time of demand. Perceptual interference has been demonstrated in laboratory studies where the ability of irrelevant peripheral stimuli to capture attention exogenously during performance of a primary task is reduced as the perceptual demands of the primary task increases.[56] Motor interference may occur when two similar motor activities are attempted simultaneously. A prototypical example of motor interference is the difficulty to tap different rhythms with the two hands. Motor interference may have important implications for the DRT, as further addressed below. In contrast to sensory/actuator interference, perceptual/motor interference is generally reduced with practice (i.e. as tasks become increasingly automatized).

Finally, *cognitive interference* occurs when several tasks place concurrent demands on cognitive control and there is an insufficient amount of resources available to support both tasks simultaneously at the time of demand. As mentioned above, all tasks, as long as they are not completely automatized, demand some degree of cognitive control. Since cognitive control can be regarded as a single limited resource, cognitive interference may arise for any combination of non-automatized tasks regardless of their perceptual/motor or sensory/actuator demands. Thus, for example, cell phone conversation (with mainly auditory/vocal demands at the perceptual/motor level) has been demonstrated to delay driver response times to external visual events (e.g. Reference [44]), an effect that thus may be attributed to cognitive load.

Returning to the examples in Figures A.2 and A.3, it may be suggested that lane keeping (in non-demanding conditions) and "purely" cognitive tasks such as hands-free phone conversation demand different resources and should thus not interfere. This is generally in line with existing research (see e.g. References [30], [59] and [63]). The model also predicts that that hands-free phone conversation would interfere with lane keeping in more demanding driving conditions. Indeed, Medeiros-Ward, Cooper and Strayer[61], in a simulator study, compared the effect of cognitive load on lane keeping in conditions with and without (simulated) wind gusts and found exactly this result.

A.4 Resource demands and task interference for the DRT

The DRT demands resources at all three levels in the general model outlined above, although these demands differ somewhat between the three DRT versions included in this document. The discussion below focuses on interference between the DRT and a secondary task, as this represents the main scope of this document. However, a similar discussion could be developed for the interference between the DRT and driving or the secondary task and driving.

— *Sensory/actuator demands*: With respect to sensory demands, the visual versions of the DRT (remote and head-mounted DRT) demand the eyes, while the tactile DRT requires mainly tactile sensing.4) With respect to actuator demands, all DRT versions require a finger to push the response button.

— *Perceptual/motor demands*: The visual versions of the DRT require visual perception to detect the stimulus, while the tactile DRT requires somatosensory perception. All DRT versions require manual motor control to execute the response.

— *Cognitive demands*: The DRT is an artificial task, generally not previously encountered by participants, and thus not heavily automatized. Hence, it demands some degree of cognitive control and this demand should be similar for all three DRT versions. However, the demand from the DRT on cognitive control can be regarded as relatively low due to the simplicity of the task.

Sensory interference should mainly occur for the remote DRT, and mainly for tasks that require movement of the eyes towards a location (e.g. a display) that is spatially separated from the remote DRT stimulus. This effect arises because high visual acuity is only available in the small part of the retina known as the fovea, which subtends about 2° of visual angle; the visual acuity degrades with increased visual eccentricity from the fovea up to the point where the stimulus appears outside the field of view. Thus, for the remote DRT, the DRT stimuli will appear in the visual periphery, or entirely outside the field of view, if gaze is directed away from the location of the DRT stimulus. This effect should be larger the more the DRT stimulus is spatially separated from the secondary task display. The head-mounted DRT should not be as sensitive to sensory interference as the remote DRT since the stimulus always appears in the same position relative to the head, and thus always within the field of view. However, if

4) In silent testing environments, the tactile DRT stimuli may sometimes also be sensed auditorily.

the eyes move relative to the head, the head-mounted DRT is also, at least in theory, subject to visual eccentricity effects, due to the reduced sensitivity in the visual periphery.

For the tactile DRT, visual eccentricity effects of visually demanding tasks are obviously eliminated, but sensory interference could still occur if the tactile vibration of the tactile DRT is masked by other body vibrations. For example, there is anecdotal evidence from an existing study,[59] where the tactor was put on the subject's neck, that vibrations resulting from speech interfered with the tactile DRT stimulus (this is the reason why this document specifies that the tactor should be put on the shoulder, where the interference from speech-induced vibrations should be reduced compared with the neck position).

Actuator interference for the DRT would occur if the hand used to give DRT responses were also needed to perform the secondary task. However, this is normally prevented by the experimental setup (where participants respond to the DRT with one hand and perform the secondary task with the other).

Perceptual interference with the DRT would be expected for secondary tasks with overlapping perceptual demands. Since, tactile perception is generally not demanded by most common secondary tasks in today's vehicles, this type of interference would mainly be expected for the remote DRT and head-mounted DRT when combined with secondary tasks demanding visual perception.

In contrast, *motor interference* could be expected to occur between all DRT tasks and secondary tasks that require manual operations similar to the DRT response (for example, frequent buttons presses when operating an in-vehicle human-machine interface). Some evidence for this effect can be found in Reference [31]. In addition, other forms of interference (as well as facilitation) may occur due to various forms of cross-modal interactions at the perceptual/motor level.[25][41] Moreover, the *Simon effect*[91] suggests that responses should be facilitated for stimuli presented on the same side as the response hand compared with stimuli presented at the opposite side. Finally, it is possible that interference occurs due to overlap between DRT perception and secondary task motor modality. For example, the tactile DRT may interfere more than the remote DRT and head-mounted DRT with a secondary task that utilizes a tactile input modality (such as a haptic knob). However, this combination of task input modality and DRT type has not yet been systematically tested in any known research to date.

Finally, all three DRT versions should be sensitive to the attentional effects of *cognitive interference* when the secondary task demands cognitive control. Since cognitive control can be regarded as a single resource, the effects of cognitive load should be similar across DRT types, which is generally confirmed by existing studies.[16][39][63]

Given that the different DRT versions vary, at least in theory, with respect to their sensory and perceptual resource demands, the potential sources of interference with the secondary task under evaluation need to be carefully considered. A task which imposes cognitive demands typically also presents a constellation of sensory/actuator and perceptual/motor demands. This means that if the goal of testing with DRT is to examine solely the effects of a task's cognitive load, a DRT version should be chosen that minimizes the overlap of a DRT's sensory, perceptual and response modalities with those of the secondary task under evaluation.

A.5 Adaptive driver behaviour and resource allocation strategies

While the resource model outlined above provides a useful tool for understanding and predicting effects on the three main DRT versions in this document, it should be pointed out that the driver should not be seen as merely a passive victim of task load. Rather, in real-world driving, a significant aspect of driver behaviour is the drivers' ability to actively manage different driving and secondary task loads in a proactive, adaptive, manner. For example, while operating a visually demanding in-vehicle information system (IVIS), drivers tend to reduce speed (e.g. Reference [22]), thus actively reducing the demand of the driving task. Moreover, the decision of drivers as to whether or when to initiate a secondary task is strongly dependent on the current or anticipated driving demand.[81]

Nevertheless, experimental dual/triple task methods, such as the DRT, are still useful to obtain measures of the attentional effects of the *potential* load imposed by a task on one or more of the resources distinguished above, once the secondary task is initiated and carried to completion. In the case of the DRT, a key potential problem related to adaptive behaviour is that drivers may deliberately sacrifice performance of some tasks in order to maintain a desired performance level on the other task(s). Thus, the potential load of the secondary task may not be accurately reflected in DRT performance due to differences in resource allocation strategies between participants. This is further illustrated in Figure A.5 and A.6 which represent the application of the DRT to the evaluation of two different tasks, Task 1 and Task 2, with different demands on the cognitive control resource (i.e. different cognitive loads). Here, it is assumed that Task 2 is more cognitively demanding than Task 1. Figure A.5 represents an "ideal" situation where the participant allocates a fixed amount of resources to the driving task in both secondary task conditions. Thus, on the further assumption that the driver attempts to perform both Task 1 and Task 2 to the best of their ability, the difference in cognitive load between Task 1 and Task 2 is directly reflected in the amount of resources left for performing the DRT and, hence, in DRT performance.

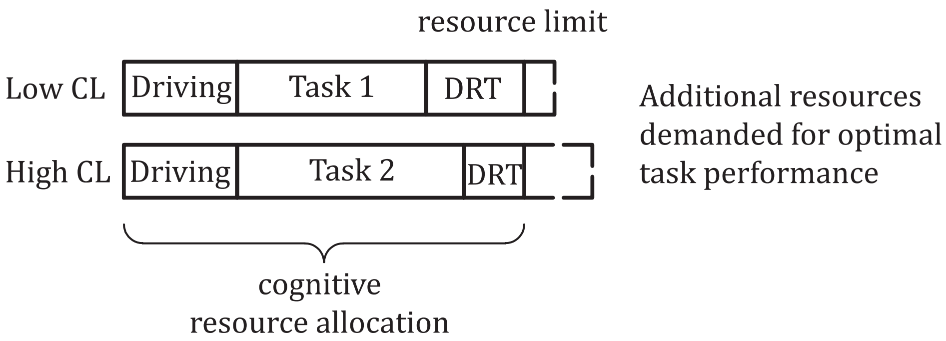


Figure A.5 — Driver cognitive resources allocation to the driving task

By contrast, in Figure A.6, the participant instead reduces the amount of resources allocated to driving (for example by slowing down) in order to provide "room" for the more demanding task (Task 2). Thus, in this case, the difference in cognitive load between the two tasks is no longer reflected in DRT performance. The same argument could be made for resource allocation to the secondary task. For example, the participant may decide to sacrifice performance on Task 2 in order to protect performance on driving and the DRT.

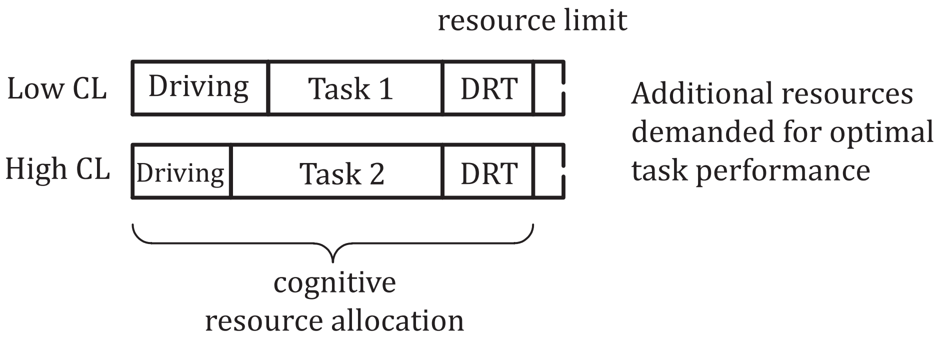


Figure A.6 — Subject resources reduction allocated to driving when facing the higher cognitive load of Task 2

This example emphasizes the importance of clear, consistent instructions on how to prioritize between the different tasks. Moreover, it shows that it is necessary to analyse not only DRT performance, but also driving and secondary task performance to check for effects of resource allocation strategies not following the task priority instructions. To obtain a complete picture of resource allocation strategies, performance of all tasks when performed alone should be measured as well as when combined with other tasks. If this analysis indicates differences in resource allocation strategies between participants and/or between task conditions, the data needs to be interpreted with caution. However, this is not feasible in applied DRT studies.

The practical implication of these issues is ultimately an empirical question. In a recent study, the effect of different task priority instructions was investigated in the context of the DRT and was found that task priority instructions actually had little effect on DRT performance.[19] This appears to indicate that, despite the strong theoretical implications of resource allocation strategies that violate task instructions, the practical consequences for the DRT methodology may be less severe. This also indicates that participants may neglect task priority instructions.

A.6 Conclusions

The conceptual framework outlined in this annex, in particular the three-level resource model illustrated in Figure A.1, is intended as a general aid for conceptualizing what is measured by the DRT. The model suggests that the DRT is potentially sensitive to specific interference at the sensory/actuator and perceptual/motor levels, as well as general cognitive interference related to concurrent demands for cognitive control (i.e. cognitive load). These predictions are generally supported by the results from the ISO-coordinated DRT studies (see Annex E), which demonstrated a reliable effect of cognitive load on response time, which was similar across DRT versions, and more specific effects of visual sensory and perceptual interference on miss rate, especially for the remote DRT. Thus, these results support the use of DRT to measure the effects of cognitive load on attention and that specific versions of the DRT may be used to measure more specific forms of interference.

In general, when conducting a DRT experiment to evaluate the task load induced by a secondary task, it is of key importance to consider the different forms of interference that may occur between the DRT and the secondary task under evaluation. If the goal is to isolate the effect of cognitive load, care should be taken to minimize other sources of interference at the sensory/actuator and perceptual/motor levels. However, the DRT may also potentially be used to capture such more specific interference effects (e.g. related to the visual eccentricity of a display).

Beyond the resource model, this annex also emphasizes the importance of considering the effects of adaptive driver behaviour, in particular task allocation strategies. This involves verifying that the task priority instructions are obeyed and evaluated not only by performance on the DRT, but also by performance on the other tasks included in the test (e.g. driving and the task under evaluation).

Annex B
(normative)

Guidelines for selecting between variants of the DRT method

B.1 General

The main body of this document specifies three variants of the DRT: the head-mounted DRT (HDRT), the remote DRT (RDRT) and the tactile DRT (TDRT). These variants differ only in terms of stimulus modality and/or stimulus location. This annex provides some general guidance for the choice of DRT version given a certain study purpose, based on the conceptual framework outlined in Annex A and the empirical results from the ISO-coordinated studies reviewed in Annex E.

As suggested in Annex A, the effect of a secondary task on DRT performance (i.e. response time or hit/miss rate) can be understood in terms of task interference resulting from competing resource demands of the secondary task and the DRT. Annex A outlines a multiple resource model with three levels: sensory/actuator resources, perceptual/motor resources and cognitive resources. As a general guiding principle, the DRT variant should be selected so that the type of interference that the study is intended to address is isolated the extent possible, thus minimizing the influence of other forms of interference. This should maximize the sensitivity, as well as the specificity for the specific task interference effect of interest in the study.

As stated in the scope of this document, the main intended application of the DRT method is to evaluate the attentional effects of cognitive load imposed by a secondary task. As described in Annex A, this relates to cognitive interference that is a competing demand for cognitive (executive attention) resources. *Thus, if the goal is to assess the attentional effects of cognitive load, the DRT version should be selected so that sensory/actuator and perceptual/motor interference with the secondary task is minimized*. Below, some more specific guidance for DRT variant selection are provided for different types of secondary tasks.

B.2 Auditory-vocal tasks

Auditory-vocal tasks generally refer to tasks where sensation and perception mainly occurs in the auditory modality (e.g. listening to spoken words) and actions are executed by means of the voice (e.g. talking or singing). “Pure” auditory-vocal tasks, such as the n-Back task used in the ISO-coordinated studies (Annex E), only compete with the DRT for cognitive resources, regardless of DRT variant (see Annex A). Hence, if the goal is to evaluate the attentional effects of cognitive load imposed by such tasks, the choice of DRT version should not matter and the DRT variant can be chosen based on practical considerations. This is also supported by the results from the ISO-coordinated studies (Annex E) which showed consistent strong sensitivity to the n-Back task for all DRT versions.

However, naturalistic auditory-vocal tasks, such as the interaction with a voice-controlled interface, generally also involve a certain degree of visual interaction (e.g. related to visual feedback on voice commands on a display). If such visual interaction is relatively infrequent, the specificity of the DRT to attentional effects of cognitive load should probably still not differ much between the DRT versions. However, if a voice interface requires frequent eye-glances to the display, the visual DRTs (RDRT and HDRT) may also be sensitive to specific sensory or perceptual interference in the visual modality. In this case, the TDRT is the preferable choice since it bypasses the visual modality and thus has the highest specificity for attentional effects of cognitive load. Further empirical work is needed to establish more precisely the extent to which the choice of DRT variants matters for the evaluation of naturalistic auditory-vocal tasks with a limited degree of visual interaction.

B.3 Visual tasks

For the evaluation of the attentional effects of cognitive load imposed by secondary tasks with a strong component of visual interaction, the TDRT is generally preferable. As described above, it minimizes visual sensory/perceptual interference and thus has the highest specificity for cognitive interference. Another advantage of the TDRT in this context is that it should not affect eye movements and thus can be used in studies involving eye tracking.

However, if the goal is to evaluate effects of visual sensory and/or perceptual demand (e.g. related to glances towards a display), the RDRT is the preferable method. As demonstrated in the ISO-coordinated studies, the hit/miss rate of the RDRT was consistently sensitive to manipulations of visual demand. The RDRT should also be suitable for evaluating effects of display position, although further empirical work is needed to demonstrate this.

As described in Annex A, the RDRT is potentially sensitive to both visual sensory and perceptual demands (in addition to cognitive demands) while the HDRT minimizes the sensory demand component (since the stimulus moves with the head). Thus, the HDRT seems preferable in studies specifically addressing visual perceptual demand independently of gaze, such as effects of display clutter and the perceptual demand of different road/infrastructure layouts (although the latter application is outside the scope of this document).

B.4 Tasks involving manual interaction

Due to the fact that the DRT requires manual interaction for executing the responses, there will always be some degree of motor interference with secondary tasks requiring manual interaction. While this effect may be problematic for very response-intensive secondary tasks (see Clause 1 and Annex E for further discussion), it should be the same across DRT variants since they all use the same response method.

B.5 Practical considerations

In addition to the theoretical considerations outlined above, the choice of DRT version may also be determined by practical constraints. For example, in studies involving long driving sessions in a simulator, the RDRT may be preferable over the HDRT and the TDRT due to its lower physical intrusiveness. If the study involves physiological measurement with sensors attached to the body, the RDRT (and to some extent the HDRT) may be easier to implement than the TDRT.

Annex C
(normative)

Additional factors affecting DRT performance

C.1 General

This annex provides guidance on factors known to influence DRT performance and hence should be kept under experimental control in DRT studies. These factors should always be reported.

C.2 Vehicle type and dynamics

When the DRT is used in on-road driving conditions, the general vehicle type (e.g. passenger car, light truck, heavy truck, bus) is likely to affect DRT performance and should thus always be reported. In simulated driving, the realism of the vehicle dynamics strongly affects driving demand and may thus influence DRT performance. Hence, the vehicle dynamics should be consistent throughout the study.

The type of vehicle transmission used in the experiment should be consistent throughout the study. If the secondary task under evaluation requires manual interaction, a manual transmission should be avoided as it may potentially interfere with the DRT measurement.

C.3 Road type

The road type (e.g. urban or rural limited access road arterial, collector, local road), as well as the road geometry, should be consistent throughout the study and reported along with key parameters such as lane width.

C.4 Road conditions

The road conditions should be kept constant. In general, dry, flat pavement is preferable and slippery conditions (such as snow or ice) should be avoided.

C.5 Traffic density

DRT tests should preferably be conducted in low to moderate traffic density (Level of Service A to B) and the measurements should be conducted during free driving, that is, the driving shall not be significantly affected by the presence of surrounding vehicles. If interfering traffic events occur, the test leader shall avoid initiating secondary tasks during this period. If a secondary task was already being performed, it should be interrupted and repeated later.

C.6 Lighting conditions

The DRT shall preferably be used in daylight conditions. When the head-mounted or remote DRT is used in real-world driving, the conspicuity of the LED may be reduced by bright sunlight. Moreover, the LED conspicuity may vary strongly due to, for example, shading trees. While such factors are difficult to control for, the lighting conditions should be reported when the head-mounted or remote DRT is used in outdoor conditions.

C.7 Visibility

The DRT should preferably be used in conditions of clear visibility and, when used in the real world, weather conditions such as fog, heavy rain or snow should be avoided.

Annex D
(informative)

DRT variants

D.1 General

This annex compiles all the various types of detection-response tasks (DRTs) that have been used historically, not just the three types described in the main body of this document. Each of these DRTs can be used for measuring driver attention and performance depending on the local context and objectives set for each context. This annex gives priority to the first implementation of each type that was identified in a literature search, and is not intended to cite the many hundreds of papers that have used the DRT or its predecessors over the past 30 years.

The variations of DRTs are classified into taxonomy according to the different sensory-motor input modalities used to present stimulus events including visual, auditory and tactile events (see Figure D.1). The visual DRTs use one or more visual probes in the forward and/or side views. Various visual DRTs have been developed since 1986 which include two classes: remote from the body (remote DRT or RDRT) or mounted on the head (head-mounted DRT or HDRT). The RDRT types include the peripheral detection task (PDT), visual detection task (VDT), the PDT+VDT and dual remote DRT (DRV-DRT). The auditory DRT (ADRT) employs sound stimuli for auditory event detection and the tactile DRT (TDRT) uses vibratory stimulation for tactile event detection.

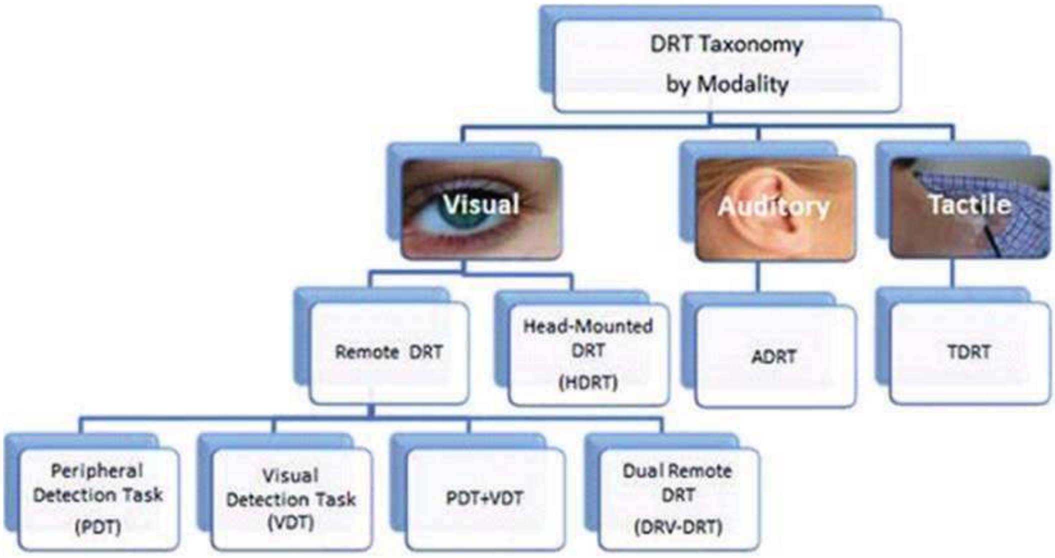


Figure D.1 — DRT taxonomy by input modality

D.2 Development and description for each DRT

D.2.1 Visual detection response tasks

The detection-response tasks associated with a visual stimulus event have been developed first among all the DRTs. Variations of the visual detection-response tasks depend on the number, position and colour of the visual events.

D.2.1.1 Remote detection response task (Remote DRT)

The remote DRT refers to the detection task of visual light(s) in a region away from the driver's body. There are several variants.

D.2.1.1.1 Peripheral detection task (PDT)

The peripheral detection task (PDT) uses one or more visual probes in the peripheral visual field (e.g. one or more red lights to the side of the driver).

D.2.1.1.2 Visual detection task (VDT)

The visual detection task (VDT) uses one forward visual probe in the central visual field above the central vehicle operation area (e.g. one forward red light).

D.2.1.1.3 Peripheral detection task-visual detection task (PDT-VDT)

The PDT-VDT is the combination of the peripheral detection task and the visual detection task with one forward and one side red light that are randomly activated in time.

D.2.1.1.4 Dual remote visual detection response task (DRV-DRT)

The dual remote visual detection response task (DRV-DRT) has one forward and one side visual probe that can be either a red or a green light appearing in one of the positions at a time. The subject is typically instructed to respond to one type (colour) of light and ignore the other.

D.2.1.2 Head-mounted detection response task (HDRT)

The head-mounted detection-response task (HDRT) is composed of one side red light secured on a head-mounted device in the peripheral visual field.

D.2.2 Auditory event detection response task (ADRT)

The detection-response task uses an auditory stimulus event, e.g. a "beep" or broadband noise.

D.2.3 Tactile event detection response task (TDRT)

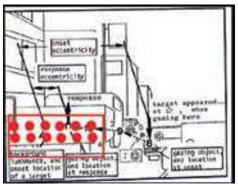
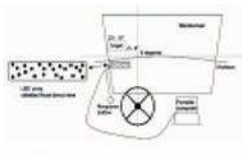
A tactile (typically vibratory) stimulus is presented on the skin of the subject. The main body of this document specifies that the stimulus should be placed on the shoulder but other studies have placed it on the neck or the wrist.

For all DRT types, the stimulus is presented with random intervals. Participants are asked to press a button as quickly and accurately as possible when they detect the stimulus (in some versions, e.g. the DRV-DRT above, the subject is instructed to respond to stimuli of a certain colour but ignore stimuli of a different colour). In this document, the button is attached to the left index finger, but a foot button or brake pedal has also been commonly used. The response times and hits and misses to the stimulus are collected.

D.3 Compendium of DRT development, implementation and citations

Table D.1 summarizes the DRT variants that have been developed throughout the 30-year history of the method. The first instance of each method cited in the literature has been described in the table, but it should be recognized that many of these types have been used by other researchers in later studies that are not cited here. Thus, the table is not a compendium of all research on the DRT, but only of the types of DRTs found in the literature. Table D.1 gives a synopsis of each implementation, along with relevant citations in a literature search of the driving safety field.

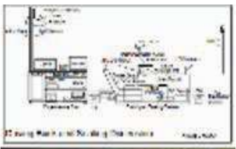
Table D.1 — Compendium of DRT development, implementation and citations

Type of DRTs	Previous studies	Description	Response modality	Photo/s	Setup
Remote visual DRT (PDT)	References [68], [69] and [70]	— A small spot of light (40 cd/ m2) served as the target and was presented spatially and temporally at random on the back of the windshield about 55 cm from participants. — The stimulus field extended about 40° wide and 20° high and the diameter of a target light spot was about 0,5°. — The participants' task was to respond to a target orally as soon as possible while driving.	Verbal response (speech) 		Open-road driving
Remote visual DRT (PDT)	References [57], [58] and [94]	Small red square in one of 23 possible positions on left driving simulator screen	Manual response (button press against steering wheel by the index finger of the dominant hand)  		Simulated driving
Remote visual DRT (PDT)	Reference [74]	The LED light in one of 23 possible positions reflected in the windshield	Manual response (button press against steering wheel by left index finger) 	 	Open-road driving

[a] This DRT type, along with those types implemented by the group of researchers involving Young, Angell, Hsieh, Seaman, et al. have been shown to be predictive of semi-naturalistic event detection during driving.[6] This provides evidence of the validity and meaningfulness of what RDRTs measure for driving, as well as providing a key link to their safety-relevance. See the identified citations for more information about this topic.

[b] This DRT variant allows the effects of task load on two different functions of attention to be assessed: the facilitative and inhibitory functions of attention.

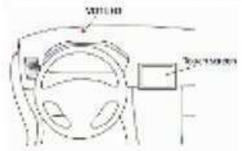
Table D.1 *(continued)*

Type of DRTs	Previous studies	Description	Response modality	Photo/s	Setup
Remote visual DRT (PDT)	References [6] and [7]	A laser projected red spot on the left of a simulator screen	Manual response (finger press on button; either hand)	 	Simulated driving
Remote visual DRT (PDT)	Reference [64]	— A red LED to left or right of screen, moving or stationary. — The visual and moving visual detection tasks consisted of a red circle (radius 29,3 mm × 30,93 mm) presented randomly to the left or right of the screen. For the moving visual DT, the red circle moved 0,1 s after its appearance, by a distance of 0,1 m and in a randomly chosen direction.	Manual response (button press against steering wheel by right index finger) 		Simulated driving
Remote visual DRT (PDT)	Reference [63]	The stimulus for the visual detection task was a 0,03-m red circle, subtending a visual angle of 0,68°. The circle was presented randomly to the left or right of the road scene, at a horizontal angle of 11° to 23° and a vertical angle of 2° to 4°above the horizon.	Manual response (button press against steering wheel by right index finger) 		Simulated driving

[a] This DRT type, along with those types implemented by the group of researchers involving Young, Angell, Hsieh, Seaman, et al. have been shown to be predictive of semi-naturalistic event detection during driving.[6] This provides evidence of the validity and meaningfulness of what RDRTs measure for driving, as well as providing a key link to their safety-relevance. See the identified citations for more information about this topic.

[b] This DRT variant allows the effects of task load on two different functions of attention to be assessed: the facilitative and inhibitory functions of attention.

Table D.1 *(continued)*

Type of DRTs	Previous studies	Description	Response modality	Photo/s	Setup
Remote visual DRT (PDT)	Reference [77]	Computer-based simulation: a small red circle in one of six possible positions on left and right simulator screen	Manual response (button press)	 	Simulated driving
Remote visual DRT (VDT)	References [15] and [33]	Non-driving vehicle simulation: a red LED reflection in central position on windshield (on road) or perceived directly (driving simulator)	Manual response (button press with left index finger) 	 	Open-road driving[33] Simulated driving[15]
Remote visual DRT (PDT+VDT)	Reference [64]	Three red LEDs in peripheral, mid-peripheral and central positions on windows	Manual response (button press against steering wheel by left index finger) 		Open-road driving
Remote visual DRT (PDT+VDT)[a]	References [5] and [107]	Red LEDs in side and forward positions outside vehicle	Pedal response (right foot brake pedal tap) 		Surrogate driving

[a] This DRT type, along with those types implemented by the group of researchers involving Young, Angell, Hsieh, Seaman, et al. have been shown to be predictive of semi-naturalistic event detection during driving.[6] This provides evidence of the validity and meaningfulness of what RDRTs measure for driving, as well as providing a key link to their safety-relevance. See the identified citations for more information about this topic.

[b] This DRT variant allows the effects of task load on two different functions of attention to be assessed: the facilitative and inhibitory functions of attention.

Table D.1 *(continued)*

Type of DRTs	Previous studies	Description	Response modality	Photo/s	Setup
Remote visual DRT (PDT+VDT)	References [5] and [107]	Two red LEDs in side (left mirror) and forward (hood) positions with sunlight shield, outside vehicle	Pedal response (right foot brake pedal tap) 		Closed-road driving
Remote visual DRT (PDT+VDT)	References [5] and [107]	To overcome sun glare, two arrays of bright blue LED lights are simultaneously activated in either side or forward positions outside vehicle with sunlight shield	Pedal response (right foot brake pedal tap) 	   	Surrogate and closed-road driving
Remote visual DRT (PDT+VDT)	Reference [108]	Two red LEDs in forward (hood) and side (top or left mirror) positions outside vehicle	Pedal response (right foot brake pedal tap) 		Surrogate driving

[a] This DRT type, along with those types implemented by the group of researchers involving Young, Angell, Hsieh, Seaman, et al. have been shown to be predictive of semi-naturalistic event detection during driving.[6] This provides evidence of the validity and meaningfulness of what RDRTs measure for driving, as well as providing a key link to their safety-relevance. See the identified citations for more information about this topic.

[b] This DRT variant allows the effects of task load on two different functions of attention to be assessed: the facilitative and inhibitory functions of attention.

Table D.1 *(continued)*

Type of DRTs	Previous studies	Description	Response modality	Photo/s	Setup
Remote visual DRT (PDT+VDT)	References [10], [11], [12], [13], [35], [36], [45], [46], [47], [48], [49], [50], [51], [52], [90], [102], [103], [104], [105], [107], [108] and [109]	A red circle randomly presented in side or centre position on simulator screen	Pedal response (right foot brake pedal tap)	 	Surrogate driving
Remote visual DRT (PDT+VDT)	References [35], [36], [103], [45], [47], [48], [49], [50], [105] and [106]	A red circle in side or central positions projected on mirror, inside fMRI brain imaging set-up	Pedal response (right foot brake pedal tap)	 	Surrogate driving
Remote visual DRT (PDT+VDT)	References [10], [11], [12], [13] and [14]	A red circle in side or central positions on simulator screen projected via screen and mirror in MEG brain imaging setup	Pedal response (right foot brake pedal tap)	 	Surrogate driving
Dual remote visual DRT (DRV-DRT)[b]	References [51], [52] and [105]	Either a red circle or a green circle in side or central positions on simulator screen	Pedal response (right foot brake pedal tap)		Surrogate driving

[a] This DRT type, along with those types implemented by the group of researchers involving Young, Angell, Hsieh, Seaman, et al. have been shown to be predictive of semi-naturalistic event detection during driving.[6] This provides evidence of the validity and meaningfulness of what RDRTs measure for driving, as well as providing a key link to their safety-relevance. See the identified citations for more information about this topic.

[b] This DRT variant allows the effects of task load on two different functions of attention to be assessed: the facilitative and inhibitory functions of attention.

Table D.1 *(continued)*

Type of DRTs	Previous studies	Description	Response modality	Photo/s	Setup
Dual remote visual DRT (DRV-DRT)[b]	Reference [106]	LED red or green lights inside left door, top of dashboard	Left foot floor button press	  	Open-road driving
Head-mounted DRT (HDRT)	References [42], [43], [77], [83] and [85]	One LED light is mounted on the left side of a headband	Manual response (button press against steering wheel by left index finger) 	 	Simulated driving
Head-mounted DRT (HDRT)	Reference [95]	One LED light is mounted on the left side of a headband	Manual response (button press with index finger; hand was not specified)		Open-road driving
Head-mounted DRT (HDRT)	References [105] and [106]	One LED light is mounted on the left side of a headband	Manual response (button press with left index finger pressing against the steering wheel) 		Open-road driving (data collected by Dynamic Research Inc.)

a This DRT type, along with those types implemented by the group of researchers involving Young, Angell, Hsieh, Seaman, et al. have been shown to be predictive of semi-naturalistic event detection during driving.[6] This provides evidence of the validity and meaningfulness of what RDRTs measure for driving, as well as providing a key link to their safety-relevance. See the identified citations for more information about this topic.

b This DRT variant allows the effects of task load on two different functions of attention to be assessed: the facilitative and inhibitory functions of attention.

Table D.1 *(continued)*

Type of DRTs	Previous studies	Description	Response modality	Photo/s	Setup
Auditory detection response tasks (ADRT)	Reference [64]	Participants were instructed to respond to auditory beeps.	Manual response (button press with left index finger pressing against the steering wheel) 		Simulated driving
Auditory detection response tasks (ADRT)	Reference [63]	The auditory detection task consisted of a burst of broadband noise presented through the car's speakers, which were located in the driver and passenger doors.	Manual response (button press against steering wheel by right index finger) 		Simulated driving
Tactile detection response task (TDRT)	References [28] and [30]	— The vibrators were put on the wrists, one on each hand. — A tactile stimulus was given to left or right wrists with random intervals.	Manual response (button press with left index finger pressing against the steering wheel) 	 	Open-road driving
Tactile detection response task (TDRT)	Reference [64]	— The vibrators were put on the wrists, one on each hand. — A tactile stimulus was given to left or right wrists with random intervals.	Manual response (button press with left index finger pressing against the steering wheel) 	 	Simulated driving

[a] This DRT type, along with those types implemented by the group of researchers involving Young, Angell, Hsieh, Seaman, et al. have been shown to be predictive of semi-naturalistic event detection during driving.[6] This provides evidence of the validity and meaningfulness of what RDRTs measure for driving, as well as providing a key link to their safety-relevance. See the identified citations for more information about this topic.

[b] This DRT variant allows the effects of task load on two different functions of attention to be assessed: the facilitative and inhibitory functions of attention.

Table D.1 *(continued)*

Type of DRTs	Previous studies	Description	Response modality	Photo/s	Setup
Tactile detection response task (TDRT)	Reference [64]	— The tactile vibrators were put in the car seat, aka "seat vibration". — The tactile stimuli were given in a random interval.	Manual response (button press with left index finger pressing against the steering wheel) 	 	Open-road driving
Tactile detection response task (TDRT)	Reference [65]	— A tactile vibrator was attached to the left neck. — The vibration of the tactor motors is also audible. — Thus, the TDRT actually provides two types of stimulation concurrently – tactile and auditory.	Manual response (button press against steering wheel by right index finger) 	 	On-road driving
Tactile detection response task (TDRT)	Reference [63]	— A tactile vibrator was attached to the left neck. — The vibration of the tactor motors is also audible. — Thus, the TDRT actually provides two types of stimulation concurrently – tactile and auditory.	Manual response (button press against steering wheel by right index finger) 	 	Simulated driving

[a] This DRT type, along with those types implemented by the group of researchers involving Young, Angell, Hsieh, Seaman, et al. have been shown to be predictive of semi-naturalistic event detection during driving.[6] This provides evidence of the validity and meaningfulness of what RDRTs measure for driving, as well as providing a key link to their safety-relevance. See the identified citations for more information about this topic.

[b] This DRT variant allows the effects of task load on two different functions of attention to be assessed: the facilitative and inhibitory functions of attention.

Table D.1 *(continued)*

Type of DRTs	Previous studies	Description	Response modality	Photo/s	Setup
Tactile detection response task (TDRT)	Reference [104]	— A tactile vibrator was attached to the left shoulder close to the neck base. — The vibration of the tactor motors is also audible. — Thus, the TDRT actually provides two types of stimulation concurrently – tactile and auditory.	Manual response (button press with left index finger pressing against the steering wheel) 		Surrogate driving
Tactile detection response task (TDRT)	Reference [104]	— A tactile vibrator was attached to the left shoulder close to the neck base. — The vibration of the tactor motors is also audible. — Thus, the TDRT actually provides two types of stimulation concurrently – tactile and auditory.	Manual response (button press with left index finger pressing against the steering wheel) 		Open-road driving (data collected by Dynamic Research, Inc.)

a This DRT type, along with those types implemented by the group of researchers involving Young, Angell, Hsieh, Seaman, et al. have been shown to be predictive of semi-naturalistic event detection during driving.[6] This provides evidence of the validity and meaningfulness of what RDRTs measure for driving, as well as providing a key link to their safety-relevance. See the identified citations for more information about this topic.

b This DRT variant allows the effects of task load on two different functions of attention to be assessed: the facilitative and inhibitory functions of attention.

Annex E
(informative)

Summary of results from the ISO-coordinated studies

E.1 General

The purpose of this annex is to provide an overview of the results from the multisite studies that were conducted in support of this document. There are similarities and differences across the sites and setups, but overall, across studies, there is strong support for the DRT as a procedure for assessing the effects of cognitive load of a secondary task on attention.

These coordinated studies were carried out by members of ISO TC 22/SC 39. Tests were conducted using the tactile DRT (TDRT), head-mounted DRT (HDRT) and remote DRT (RDRT) for four designated tasks and a baseline condition, according to specifications in the main body of this document. The objective was to investigate whether tests of secondary tasks using the DRT methods in this document can produce reliable and valid results across different sites and setups.

E.2 Key research questions

Question 1: To what extent are different RT results obtained with the DRT during non-driving, surrogate driving, driving simulator and on-road setups?

Question 2: To what extent are different RT results obtained with the TDRT, HDRT and RDRT?

Question 3: Is the DRT RT *sensitive* and *specific* to the attentional effects of low vs. high levels of cognitive load for auditory-vocal and visual-manual tasks?

Question 4: To what extent are the results for hits/misses consistent with those for RTs?

E.3 Methods

E.3.1 Sites

Table E.1 shows the eight sites that provided data for the coordinated studies analysis. The cross-site analyses were carried out by Wayne State University.

Table E.1 — Eight international sites that provided DRT test data for the cross-site analysis

No.	Site	Name	Country	Citation
1	WSU	Wayne State University	USA	Young et al. (2013[104])
2	IFSTTAR	French Institute of Science and Technology for Transport, Spatial Planning, Development and Networks	France	Bruyas & Dumont (2013[16])
3	TC	Transport Canada	Canada	Harbluk et al. (2013[39])
4	DRI	Dynamic Research, Inc.	USA	Kirsch & Chiang (2012[55])
5	JCI	Johnson Control, Inc.	Germany	

a Reference [20] describes the experimental setup only.

Table E.1 *(continued)*

No.	Site	Name	Country	Citation
6	MIROS	Malaysian Institute of Road Safety Research	Malaysia	Mohd Firdaus et al. (2014[71])
7	TUM	Technical University of Munich	Germany	Conti et al. (2013[20])[a]
8	Volvo	Volvo AB	Sweden	Engström et al. (2013[31])

[a] Reference [20] describes the experimental setup only.

E.3.2 Test parameters

Table E.2 shows the test parameters at each site. The first four sites provided a complete data set by testing all three DRTs (TDRT, HDRT and RDRT) and providing the participant-level data needed for a cross-site analysis of variance. The data from these four sites were the data used for the main cross-site comparison. Site 5 tested only the HDRT, sites 6.1 and 8 tested only the TDRT, site 6.2 tested both the TDRT and the HDRT and participant-level data were not available from site 7. The subsidiary data from sites 5 to 9 are shown for comparison to the main data set from sites 1 to 4 where relevant.

Table E.2 — DRT test parameters at the coordinated sites

No.	Site	Setup	TDRT	HDRT	RDRT	n-Back levels	SuRT levels	n	Trial duration min	No. of trial replications	Exposure min
1	WSU	Surrogate	TNO	TNO-L	1 left	0,1	E, H	16	2	2	4
2	IFSTTAR	Simulator	TNO	TNO-L	1 centre	0,1	E, H	16	1	1	1
3	TC	Simulator	TNO	TNO-L	1 off-centre	0,1	E, H	16	1	1	1
4	DRI	On-road	TNO	TNO-L	1 left	0,1	E, H	15	1,5	2	3
5.1	JCI	Simulator	—	TNO-L	—	—	E, H	20	1	1	1
5.2	JCI	Non-driving	—	TNO-L	—	—	E	20	1	1	1
6.1	MIROS	On-road	TNO	—	—	0,1	—	16	Varied	1	Varied
6.2	MIROS	Simulator	TNO	TNO-R	—	0,1	E, H	30	1	1	1
7.1	TUM	Simulator	Custom	Custom-L	4 off-centre	0,2	E, H	18	1	1	1
7.2	TUM	Non-driving	Custom	Custom-L	4 off-centre	0,2	E, H	18	1	1	1
8.1	Volvo	Simulator	Custom	—	—	0,1	E, H	16	1	2	2
8.2	Volvo	Non-driving	Custom	—	—	0,1	E, H	18	1	2	2

E.3.2.1 Setups

Table E.2, column 3 “Setup”, indicates whether laboratories used non-driving, surrogate, simulator or on-road testing conditions.

E.3.2.2 DRTs

Columns 4 to 6 in Table E.2 show the DRTs used at each site. Sites 1 to 4 and 6 used the tactile DRT (TDRT) developed by TNO in the Netherlands and sites 7 and 8 used custom TDRTs. Sites 1 to 5 and 6.2 used the head-mounted DRT (HDRT) from TNO. The HDRT light was presented on the left for sites 1 to 5 and on the right for site 6.2 since they have right-hand drive in Malaysia. Site 7 used a custom HRDT. Sites 1 to 4 and 7 used the remote DRT (RDRT). It had a single red light in the left position for two sites (1 WSU, 4 DRI), in the off-centre position for one site (TC) and in the centre for one site (2 IFSTTAR). In addition, one site (7 TUM) used four off-centre red RDRT lights. Five sites (1 to 4 and 7) tested all three DRT types, one site (6.2 MIROS) tested only the TDRT and HDRT, two sites (6.1 MIROS and 8 Volvo) tested only the TDRT and one site (5 JCI) tested only the HDRT.

E.3.2.3 Tasks

The two tasks selected for use in this document were the auditory-vocal *n-Back* task[62][82] and the visual-manual *surrogate reference task* (SuRT[60]).

The *n-Back* task has auditory and vocal loads but no visual or manual loads. It is a fixed-pace memory recall task using single numerical digits that is designed to measure continuous memory recall performance in a given time period. The spoken digits were presented by a loudspeaker at a fixed interval for a 1- or 2-min trial period. In the 0-Back task, participants verbally repeated the last number heard. In the 1-Back task, they repeated the number that was heard just before the last number heard (or in the case of 2-Back, two numbers before the last number heard). The n-Back task therefore has a pure auditory (listening) and verbal (vocalizing single digits) load, without visual or manual load. It is well established from cognitive neuroscience brain imaging experiments that the cognitive load is higher with 1-Back and 2-Back than with the 0-Back task due to the greater demand on short-term verbal memory, which overlaps with the cognitive control (executive attention) network in the brain (see Annex A). This greater attentional demand arises from several factors. The subject shall inhibit the response to the immediately heard digit, delay the response before reporting the digit just before the last digit heard and manage the conflict between the rehearsals of digits in memory at the same time that new digits are being heard in auditory form.

The *SuRT* is a self-paced search task that has visual and manual loads with no auditory or verbal loads. Participants scanned a display of circles on a screen with one larger “target” circle with a bolder stroke-width than the “distractor” circles. The target and distractor circle differences were easier to visually discriminate for Easy SuRT than that for Hard SuRT condition. Participants pressed the left-right keypad buttons to move the grey outline bar to the region that contained the target circle and pressed the “enter” key to confirm their selection. The self-pacing of SuRT also likely imposes a load on cognitive control to determine and manage the rate and intervals at which screens are completed (a cognitive control component of SuRT that is often overlooked). In addition, cognitive control is required in the SuRT task to decide the timing of when to press the right-hand button for the self-paced SuRT task, vs. when to press the left-hand button to respond to the machine-paced DRT stimulus, whether tactile or visual.

All sites tested 0-Back and 1-Back except site 7 (TUM), which substituted 2-Back for 1-Back. Six sites (1 to 4, 6.2 and 7) also tested SuRT. Thus, six sites (1 to 4, 6.2 and 7) tested all five main task conditions: two levels of the n-Back task, two levels of SuRT and a baseline condition with no secondary task. Only four sites (1 to 4) tested all five task conditions and all three DRT types, and also supplied participant-level data. These data were therefore used for the main overall analysis of variance. The data from sites 5 to 8 were cited where relevant to this main analysis.

E.3.2.4 Tasks by setup

The *surrogate*, *simulator* and *on-road* setups were “triple-task” conditions, meaning that participants performed driving or surrogate driving, the DRT and the secondary task. The *baseline condition* for this triple-task condition was the dual-task condition of driving (or surrogate driving), while performing the DRT. That is, the baseline condition had no secondary n-Back or SuRT. The *non-driving* setup was only a dual-task condition, with no on-road, simulated or surrogate driving, having just the DRT and the secondary task. The baseline for the non-driving setup was the single-task condition of the DRT alone with no secondary task or driving of any kind (on-road, simulated or surrogate).

E.3.2.5 Trial duration, repetitions and exposure time

Five sites (2 IFSTTAR, 3 TC, 5 JCI, 6.2 MIROS and 7 TUM) used the trial duration of 1 min, specified as the minimum in the draft standard at the time of testing. They also used a single trial, resulting in a total DRT and task exposure time of 1 min per participant (column 12 in Table E.2) which is about 15 DRT stimuli on average per task. One site (6.1 MIROS road) also used one trial, but had a trial duration that was 4 min for baseline and 2,5 min for tasks. Both Volvo sites (Volvo 8.1 and 8.2) used 1-min trials with two repetitions, for 2 min of total DRT and task exposure time per subject. Site 4 DRI had a 1,5-min trial time with two repetitions, for 3-min exposure time. Site 1 WSU had 2-min trials with two repetitions for 4 min of DRT and task exposure time per subject.

Longer exposure times present more DRT events and have more responses, reducing the uncertainty ranges in the response time (RT) and the proportions of misses and hits. Longer exposure times also give the participants more experience in performing the tasks and DRT while driving which may also reduce variability in the estimates.

E.4 RT results (questions 1 to 3)

A global ANOVA was carried out with results from the four sites that provided complete data. The experimental design included one between-participants factor (the four sites) and two within-participants factors: the DRT (TDRT, HDRT and RDRT) and the tasks (baseline, N0, N1, SE, SH). Repeated measures ANOVAs were carried out for response time analyses and are summarized below. Statistical procedures were performed with STATA.

All main effects were statistically significant:

— Site (F = 2,69, df = 3, p < 0,001): results from WSU and IFSTTAR are significantly different than those from TC and DRI;

— DRT (F = 22,27, df = 2, p < 0,001): significantly faster RTs are obtained for TDRT than for HDRT and for HDRT than for RDRT;

— Task (F = 178,73, df = 4, p < 0,001): all four secondary tasks have longer RT than baseline; N1 has longer RT than N0; SuRT tasks have longer RTs than n-Back tasks; no statistically significant differences are obtained between SE and SH.

All two-way interaction effects were statistically significant:

— Site × DRT (F = 4,17, df = 6, p < 0,001): DRT main effect has different pattern at different sites, giving rise to the interaction between site and DRT type;

— Site × Task (F = 3,84, df = 12, p < 0,001);

— DRT × Task (F = 3,16, df = 8, p = 0,002).

The three-way interaction was not statistically significant:

— Site × DRT × Task (F = 0,94, df = 24, p = 0,5467).

E.4.1 TDRT RT results

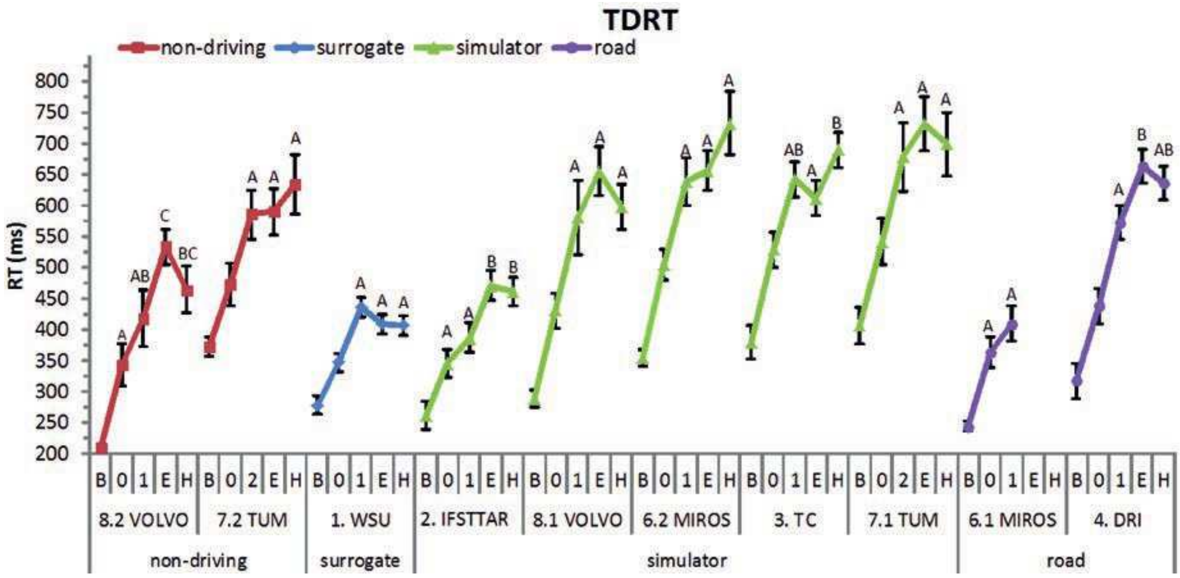
Figure E.1 presents the mean RT results for tasks at each of the 10 sites and setups that used the TDRT. As can be seen, all sites and setups have similar relative profiles across tasks for the TDRT RT results.

Statistical analyses were conducted to compare the mean RTs within each laboratory and setup combination. Paired *t*-tests were used to conduct these analyses so that a similar method could be used for each analysis at each site regardless of whether or not participant-level data were available. Conditions labelled with the same letter (A, B or C) did not differ significantly.

It should be noted that different statistical approaches to these comparisons could result in slightly different results.

E.4.1.1 N-Back TDRT RT results

Figure E.1 shows that the baseline (B) consistently has the shortest RT, 0-Back has the next longer and 1-Back (or 2-Back for the 7 TUM site) has the longest RT. Seven of the 10 site and setup combinations easily discriminated 1-Back from 0-Back. The exceptions were 8 Volvo (non-driving), 2 IFSTTAR (simulator) and 6.1 MIROS (road). Yet even here, the RTs were in the expected direction with longer 1-Back RTs than those for 0-Back, suggesting that with more or longer trials and/or more test participants, these sites might also discriminate 1-Back from 0-Back.



Key

0 0-Back
1 1-Back
2 2-Back
B baseline
E SuRT easy
H SuRT hard

Figure E.1 — RT for TDRT by task condition, for all sites and setups in the cross-site studies

Error bars are standard errors across participants for that site and setup. Task conditions sharing a letter label are not significantly different at the $p = 0,05$ level within each of the 10 sites and setups.

E.4.1.2 SuRT TDRT RT results — Easy vs. Hard SuRT

Reaction times typically did not differ significantly between the Easy SuRT and Hard SuRT conditions at each site and setup. The one exception was site 3 TC where longer RTs were observed for the Hard SuRT compared with the Easy SuRT.

E.4.1.3 SuRT TDRT RT results — SuRT vs. n-Back

In all cases, the SuRT conditions had mean RTs that were either greater than, or not statistically different from, the 1-Back task. For 7.2 TUM non-driving, 1 WSU, 8 Volvo, 6.2 MIROS and 7.1 TUM simulators, Easy and Hard SuRT did not differ statistically from 1-Back. In other comparisons, the SuRT conditions had longer RTs than the 1-Back tasks.

E.4.1.4 Excellent relative validity: Correlation analysis for TDRT RTs

Correlation analyses of the five task means for the nine sites and setup combinations that use the TDRT[5)] confirm the visual similarity of the task RT patterns in Figure E.1. Table E.3 shows that correlation coefficients ranged from 0,842 to 0,998. All correlation coefficients in Table E.3 are statistically significant at $p < 0,05$ (except the minimum 0,842, which is marginal at $p = 0,07$). This indicates that the relative pattern of RTs across tasks is similar due to the fact that they increase across conditions. However, it does not indicate that the actual RTs are the same (as can be seen in Figure E.2), it simply reflects the ordering of the means. Nor does it indicate if the differences between the means in either group differ in any significant way. This is accomplished by the statistical testing of the means.

Table E.3 — TDRT RT: Pairwise correlations for the five tasks at the nine sites and setups

No.	TDRT	WSU	IFSTTAR	TC	DRI	MIROS *Sim*	TUM *Sim*	TUM *NonD*	Volvo *Sim*	Volvo *NonD*
1	WSU	1	0,842	0,946	0,913	0,923	0,953	0,944	0,943	0,882
2	IFSTTAR	0,842	1	0,903	0,984	0,952	0,963	0,944	0,962	0,981
3	TC	0,946	0,903	1	0,929	0,987	0,944	0,987	0,924	0,883
4	DRI	0,913	0,984	0,929	1	0,966	0,993	0,970	0,992	0,985
6.2	MIROS*Sim*	0,923	0,952	0,987	0,966	1	0,964	0,998	0,949	0,923
7.1	TUM*Sim*	0,953	0,963	0,944	0,993	0,964	1	0,973	0,998	0,980
7.2	TUM*NonD*	0,944	0,944	0,987	0,970	0,998	0,973	1	0,960	0,926
8.1	Volvo*Sim*	0,943	0,962	0,924	0,992	0,949	0,998	0,960	1	0,986
8.2	Volvo*NonD*	0,882	0,981	0,883	0,985	0,924	0,980	0,926	0,986	1

The results in Table E.3 indicate that any given setup and site can make excellent predictions for the RT results for any other setup and site using simple linear regression with the same relative relationships between tasks for the nine sites and setup combinations that tested the five task conditions using TDRT. There was excellent relative validity for all sites and setups that used the TDRT.

E.4.1.5 Poor absolute validity: TDRT RTs differ among sites and setups

It is apparent from visual inspection of Figure E.1 that the absolute RTs differed considerably between the sites and setups for TDRT, despite their excellent relative validity. For example, the "1 WSU surrogate" setup has short RTs and the "7.1 TUM simulator" setup has long RTs. The differences between the RTs at these sites are actually larger than the differences between the task conditions within each site (see Figure E.1). Since the TDRT stimulus and response device and analysis methods are quite similar for these sites, these absolute TDRT RT differences between sites and setups may be due to setup differences and possibly subtle and unknown procedural or demographic differences, despite best efforts at all sites to follow the requirements within this document as closely as possible.

5) Site 6.1 "MIROS road" did not collect data for SuRT and hence could not be used for the correlation analysis.

This type of finding is not surprising and is commonly found. The literature often notes that there are major differences in the results obtained for on-road driving vs. simulated driving. Here, we also see differences between results within type of setup, two simulator studies and two road studies. For example, it is apparent from Figure E.1 that even within the simulator setups, there is considerable variation in the absolute values of the RTs (compare 2 IFSTTAR with 6.2 MIROS). Likewise, the road setup 6.1 MIROS has substantially lower RTs than the road setup 4 DRI for the baseline and n-Back tasks tested. Indeed, the low absolute values of the 2 IFSTTAR simulator setup actually appear more consistent with the 6.1 MIROS road setup than the other four simulator setups (8.1, 6.2, 3 and 7.1). In addition, the “1 WSU surrogate” setup is best matched in absolute RT values by “2 IFSTTAR simulator” setup and “6.1 MIROS road” setup. Differences in absolute RTs are not attributable to on-road driving vs. simulated or surrogate driving. Furthermore, triple-task conditions, if run at the same site with the same equipment, are well known to have longer RTs than dual-task (non-driving) setups (compare 8.2 Volvo non-driving with 8.1 Volvo simulator and 7.2 TUM non-driving with 7.1 TUM simulator). This is because of the higher attentional cost required to perform three tasks instead of two. However, the triple-task 1 WSU surrogate, 2 IFSTTAR simulator and 6.1 MIROS setups all have lower RTs than the dual-task non-driving 8.2 Volvo and 7.2 TUM (except for the baseline for 8.2 Volvo). These results show that the discrepancies in the absolute RT values do not arise from differences in non-driving, surrogate, simulated and on-road driving.

Are these absolute RT discrepancies instead explainable by different equipment and methods used by the different sites? This explanation seems unlikely. MIROS presumably used the same TDRT and n-Back methods for its simulator study (6.2) and road study (6.1). Yet their road study (6.1) had substantially shorter RTs than their simulator study (6.2) for baseline, 0-Back and 1-Back. However, Volvo conducted both non-driving and simulator setups (compare 8.2 Volvo non-driving with 8.1 Volvo simulator) with the same custom DRT tool, yet obtained quite different results from the two setups. Likewise, TUM used a non-driving setup (7.2 TUM) and a simulator setup (7.1 TUM) with their custom DRT and task conditions, differing only in whether driving occurred or not. As with the Volvo test, the non-driving setup had lower RTs than the simulator setup. This result would seem to indicate on a surface examination that the non-driving vs. driving setups could explain why there are such large differences in absolute RTs across sites and setups. However, closer examination of the data shows again that, as pointed out in the previous paragraph, three triple-task sites (1 WSU surrogate, 2 IFSTTAR simulator and 6.1 MIROS road) had lower overall RTs than either of the dual-task non-driving setups (8.2 Volvo and 7.2 TUM). The discrepancies and inconsistencies in absolute RT values between sites and setups are larger than the differences between dual-task and triple-task conditions.

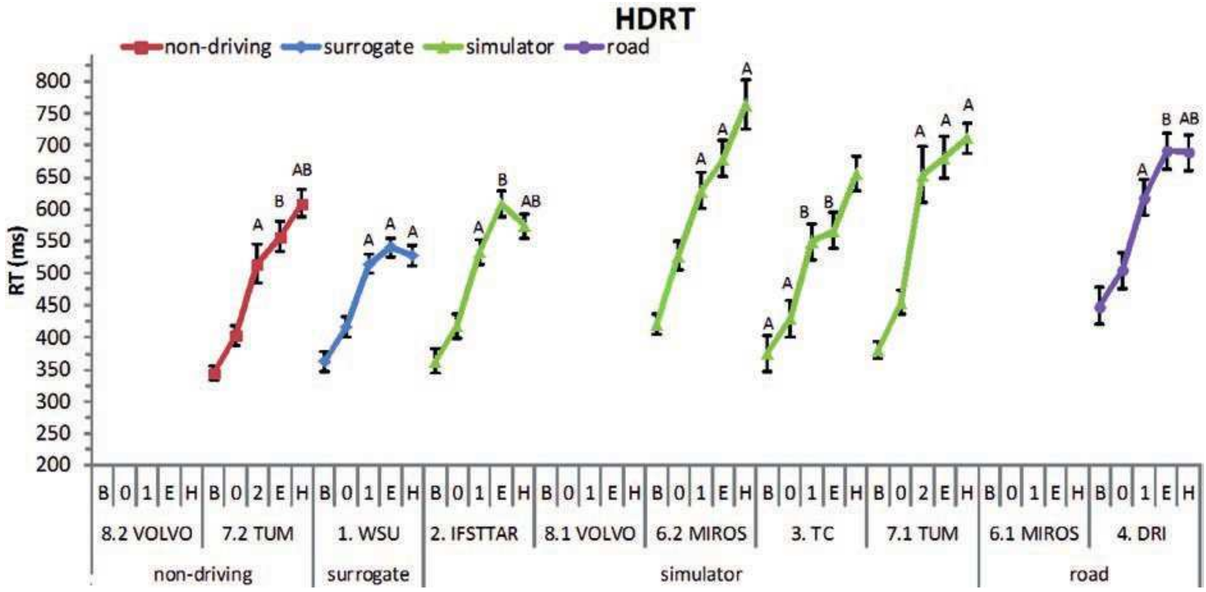
Could there be differences in the demographics of the participants between sites, which can bias the absolute values of the RTs either higher or lower at any given site? For example, the Volvo site used only men, aged 30 to 50, with a commercial truck driver’s license. However, the other sites used a balance of men and women, all of whom had only standard driver’s licenses and similar age ranges. Although there are may be cultural differences between the people in the many countries represented in this cross-site study, the RT is a fundamental human characteristic and there is no known evidence that RT varies substantially between people of different background or genetic make-up, assuming age is controlled for. Furthermore, three sites (Volvo, TUM and MIROS) tested people with the same nationality and found major differences in the absolute RTs, with MIROS finding lower RTs in the road test than in the simulator.

It has been well established since the 19th century that RT varies with stimulus intensity. Could it be that tactor intensity varied substantially between sites? The intensity might be stronger at the Volvo site because it used a custom tactor, explaining its record low 200 ms mean RT for the baseline no-driving condition. TUM also used a custom tactor. However, this explanation is not valid for the other five sites, all of which used the identical tactor from TNO in the Netherlands. It is also doubtful that slight variations in the placement of the tactor on the shoulder can explain the results because these would likely vary randomly from person to person as much or more than from site to site. A few participants occasionally find the tactor uncomfortable at first, and request it be repositioned, but such individual differences would also likely be random across sites and average out.

Thus, there is no obvious explanation of why the absolute RTs for TDRT are inconsistent between setups and sites in this cross-site study. An unexplainable variation in absolute RTs between sites is consistent with previous DRT research.[102][103] The implications of this mixed TDRT result (excellent relative validity but poor absolute validity) are that valid acceptance criteria shall be based on relative rather than absolute RT criterion, as explained further in the discussion section of this annex.

E.4.2 HDRT RT

Figure E.2 presents the results for all sites that used the HDRT, for the setup or setups that were used at each site.



Key

0 0-Back
1 1-Back
2 2-Back
E SuRT easy
B baseline
H SuRT hard

Figure E.2 — RT for HDRT by task condition and setup

Error bars are standard errors across participants. Task conditions sharing a letter label are not significantly different at the $p = 0{,}05$ level within each site and setup condition.

The HDRT relative RT results in Figure E.2 are consistent with the TDRT RT results in Figure E.1 in that the same increase in RT is observed from baseline to 0-Back to 1-Back, with a levelling off for easy vs. Hard SuRT.

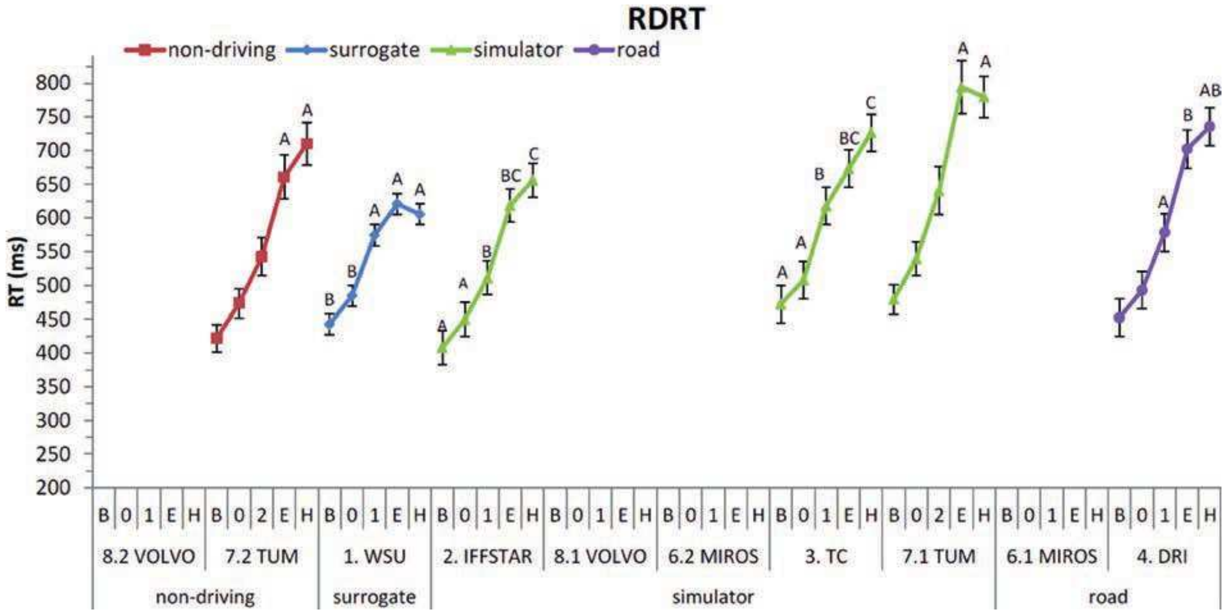
The similarity of these relative patterns for HDRT across all sites and setups is confirmed by a correlation analysis of the five task means for each combination of site and setup against the task means for every other combination site and setup. Table E.4 shows that the correlation coefficients ranged from 0,921 to 0,993 and each comparison was statistically significant at $p < 0{,}05$, indicating excellent relative validity for all seven sites and setups that used the HDRT. This indicates that the relative pattern of RTs across tasks is similar due to the fact that they increase across conditions. However, it does not indicate that the actual RTs are the same (as can be seen in Figure E.3), it simply reflects the ordering of the means. Nor does it indicate if the differences between the means in either group differ in any significant way. This is accomplished by the statistical testing of the means.

Table E.4 — HDRT RT: Pairwise correlations for the five tasks at the seven sites and setups

No.	HDRT	WSU	IFSTTAR	TC	DRI	MIROS*Sim*	TUM*Sim*	TUM*NonD*
1	WSU	1	0,988	0,932	0,982	0,941	0,989	0,962
2	IFSTTAR	0,988	1	0,921	0,993	0,934	0,976	0,960
3	TC	0,932	0,921	1	0,957	0,991	0,971	0,993
4	DRI	0,982	0,993	0,957	1	0,966	0,985	0,985
6.2	MIROS*Sim*	0,941	0,934	0,991	0,966	1	0,966	0,992
7.1	TUM*Sim*	0,989	0,976	0,971	0,985	0,966	1	0,985
7.2	TUM*NonD*	0,962	0,960	0,993	0,985	0,992	0,985	1

E.4.3 RDRT RT

Figure E.3 presents the results for all sites using the RDRT for the setup or setups. The RDRT results are similar to those for the TDRT in Figure E.1 and HDRT in Figure E.2 in that the same increasing pattern in RT is observed from baseline to 0-Back to 1-Back, with a levelling off for SuRT.



Key

0 0-Back
1 1-Back
2 2-Back
B baseline
E SuRT easy
H SuRT hard

Figure E.3 — Task condition by setup and site for RDRT

Error bars are standard errors across participants. Task conditions sharing a letter label are not significantly different at the p = 0,05 level within each site and setup condition.

The similarity of these patterns for RDRT across all sites and setups is confirmed by a correlation analysis of the five task means for each of the six sites and setup combinations that used RDRT. Table E.5 shows that the correlation coefficients ranged from 0,933 to 1,000[6] and all were statistically significant at p < 0,05. This result is despite the fact that there was variation in the RDRT setup at the different sites that used it; namely, right to left or centred relative to the driver's forward view, or one or four lights (see Table E.2, column 6). There has been excellent relative validity for all six sites and setups that used RDRT. This finding indicates that the relative pattern of RTs across tasks is similar due to the fact that they increase across conditions. However, it does not indicate that the actual RTs are the same (as can be seen in Figure E.3), it simply reflects the ordering of the means. Nor does it indicate if the differences between the means in either group differ in any significant way. This is accomplished by the statistical testing of the means.

Consistent with the findings from the TDRT and HDRT RT data, there is relatively poor absolute RT agreement between sites that used a simulator set up for RDRT.

Table E.5 — RDRT RT: Pairwise correlations for the five tasks at the six sites and setups

No.	RDRT	WSU	IFSTTAR	TC	DRI	TUM*Sim*	TUM*NoD*
1	WSU	1	0,935	0,961	0,947	0,972	0,933
2	IFSTTAR	0,935	1	0,981	0,999	0,984	1,000
3	TC	0,961	0,981	1	0,985	0,970	0,982
4	DRI	0,947	0,999	0,985	1	0,990	0,998
7.1	TUM*Sim*	0,972	0,984	0,970	0,990	1	0,982
7.2	TUM*NonD*	0,933	1,000	0,982	0,998	0,982	1

E.4.4 Comparison of mean RTs for different DRT types

The analyses discussed in this subclause are the results of the global ANOVA conducted on the data from the four sites as described in E.4 with complete participant-level data for all three DRT types and the five testing conditions.

Figure E.4 shows the DRT main effect (F = 22,37, df = 2, p = 0,001). This analysis compares only the first four sites in Table E.1 with complete subject data for all DRT types and tasks. These four sites used the identical three DRT types for all five task conditions and have similar test parameters (see Table E.2). In addition, the same participants are used for all three DRT types at each site, ruling out any confounding by demographic variables. Therefore, the differences between the DRT types evident in Figure E.5 shall come about from inherent properties of the DRT types themselves and not from extraneous factors.

6) Note that the strong correlation between 7.2 TUM and 2 IFFSTAR is because the relative pattern across task conditions is nearly identical and not because the absolute RTs are the same, as can be seen in Figure E.3. The correlation coefficient subtracts the means and standardizes the variables, so it ignores any absolute differences between variables. It simply reflects the ordering of the means. As such, it does not indicate if differences between means in either group differ in any significant way. This is accomplished by the statistical testing of the means.

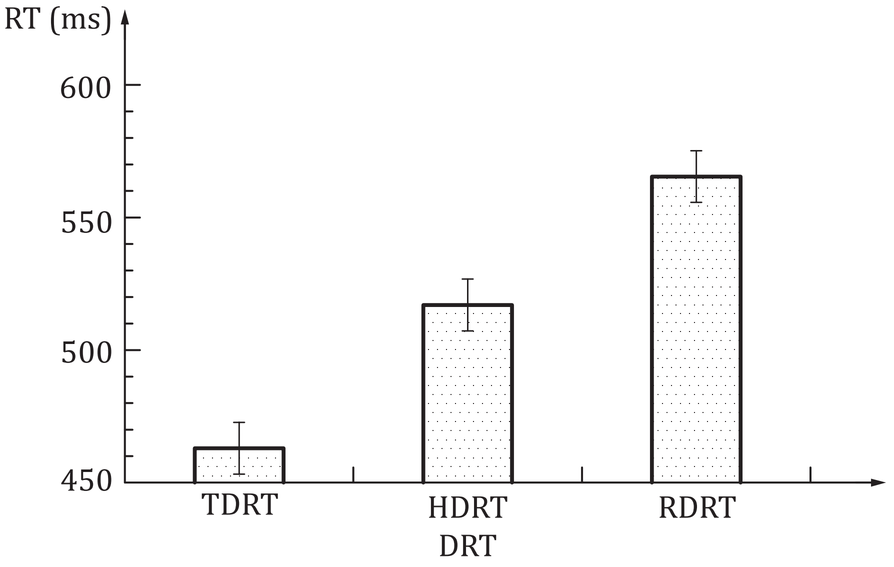


Figure E.4 — DRT main effect

Figure E.4 shows that the absolute mean RT for TDRT is less than HDRT, which is less than RDRT. Specifically, TDRT has about a 50 ms faster RT than HDRT and HDRT has about a 50 ms faster RT than RDRT, when collapsed across the first four sites and setups in Table E.1, and all five task conditions. The effect is highly significant statistically, even with the small effect size, because of the large "n" when all the data are collapsed across sites and DRT conditions.

E.4.5 DRT × task interaction for RTs

Figure E.5 shows that the RT trends across tasks were generally similar for the different DRTs (again the interaction effect was analysed only for those sites that provided complete subject data for all three DRT types).

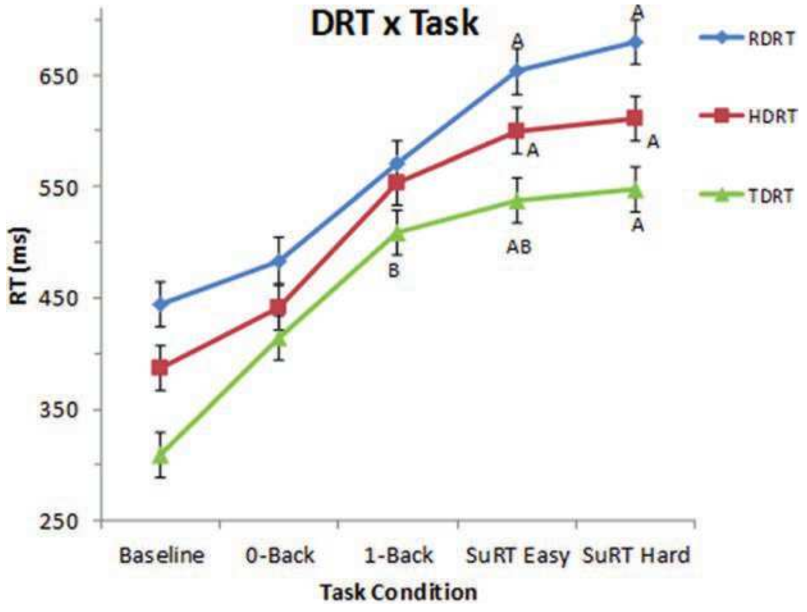


Figure E.5 — DRT × task interaction

Error bars are 95 % CIs. Within a DRT type, tasks sharing a letter label are not significantly different at the p = 0,05 level. The interaction was calculated across the sites 1 to 4 that conducted all DRT types across all task conditions and supplied subject-level data. Figure E.5 shows that the main effect of DRT type (TDRT < HDRT < RDRT) occurs across all task conditions. It also shows that the main effect of task (Baseline < 0-Back < 1-Back and Hard SuRT approximately Easy SuRT) was similar across all DRT types.

The statistically significant interaction (i.e. a difference in task profile across DRT type; $F = 3{,}16$, df = 8, $p = 0{,}002$) is not immediately obvious from visual inspection of Figure E.5. A significant interaction means that the three curves in Figure E.5 are not parallel. The only statistically significant difference that might help explain the interaction effect is that 1-Back did not have a statistically significant difference from Easy SuRT for the TDRT (red arrows in Figure E.5) and both task conditions share the letter "B", meaning they are significantly different. However, RDRT (blue diamonds) and HDRT (red squares) both found that Easy SuRT had a slightly longer RT than 1-Back by about 25 ms.

E.5 Discussion of results for RT (questions 1 to 3)

E.5.1 Answer to question 1

Question 1 asked, "To what extent are different RT results obtained with the DRT during non-driving, surrogate driving, driving simulator and on-road setups?" The answer given by the cross-site study results is that the same relative pattern of RT results is obtained with non-driving, surrogate driving, driving simulator and on-road setups. However, the absolute RTs are substantially different between sites, as well as between setups within a site. These absolute differences between sites and setups are found regardless of whether TDRT, HDRT or RDRT were used. This finding is consistent with previous driver behaviour literature, which provides strong evidence that absolute RTs will vary between experiments conducted in the laboratory vs. road venues. However, the RTs in a road test can be reliably and accurately predicted (e.g. by using simple linear regression, which corrects for variations in absolute RT) by a laboratory test using the same tasks (e.g. References [5], [6], [102], [103] and [104]). That is, different setups and sites in driver performance research have excellent relative validity, but poor absolute validity. This holds true not just for the DRT, but also for many other driver performance metrics.[5][6][102][103][113]

E.5.2 Answer to question 2

Question 2 asked, "To what extent are different RT results obtained with the TDRT, HDRT and RDRT?" The answer given by these cross-site study results is that faster absolute RTs are obtained with the TDRT than with the HDRT and with the HDRT than with the RDRT. This result is consistent with the findings in Reference [63] that the TDRT gives rise to a faster response than the RDRT. However, it is important to note that despite these absolute RT differences between DRT types, the same relative RT results are obtained regardless of the DRT type.

E.5.2.1 Why is there a faster response to TDRT than to HDRT or RDRT?

A simple explanation for the more rapid TDRT RTs vs. HDRT or RDRT RTs is that there are inherently faster RTs for tactile stimuli (e.g. TDRT) than visual stimuli (e.g. HDRT and RDRT), all else being equal. This fact has been known for a century and half.[40] Woodworth and Schlosberg[100] state, *it has almost universally been found that response to light has a longer latency than that to sound or to a touch on the skin*. That is, the TDRT uses the tactile sense, which has an inherently faster RT than the visual sense, all else being equal.

Of course, "all else being equal" is an important qualifier. The faster RTs for touch vs. vision occur when, for example, the intensities of both stimuli are above threshold. In general, RT varies with the intensity of a stimulus, no matter what sensory modality is used. Therefore, it is possible that a weak tactile stimulus could have a slower RT than a strong visual stimulus. In addition, the standard TDRT as used in most of the multisite experiments also emits an audible sound that can be heard by many participants when it is activated, particularly in the standard shoulder or neck attachment position where the tactile vibrator is near the ear. The bimodal combination of two sensory modalities will always have a shorter RT than a unimodal stimulus in either sensory modality alone[23] because of mathematical probability laws. The combined effect will be particularly beneficial if the bimodal stimuli are superimposed in time and space, as is the case with the TDRT. One can avoid this bimodal effect by reducing the intensity of the auditory component of the TDRT by placing the TDRT tactor in a soundproof enclosure. However, this would also reduce the intensity of the tactile stimulus, which would lengthen the RT to it. The loss of both the auditory component and the lowered intensity of the tactile component could make the response to the tactile stimulus actually slower than that to the visual stimulus in the HDRT and RDRT, the reverse of what was found in all the cross-site experiments here.

E.5.2.2 Why is there a faster response to HDRT than to RDRT?

The faster RT for HDRT than RDRT cannot be explained by a difference in response latencies between sensory systems because both HDRT and RDRT use light stimuli.

One explanation is that HDRT is in the “ego-zone” of attentional space and is given higher priority than stimuli in peripersonal or extrapersonal space (see Figure E.11). Since stimuli in the “ego-zone” of attentional space are given higher priority or increased salience, they may be responded to more rapidly than stimuli in the farther-away regions.

Another explanation is because the RDRT RT can be increased by head and eye movements that place the direction of gaze so far away from the forward gaze for some participants that, unless the subject happens to glance back to the forward view, the visual stimulus does not fall on the retina for a period. That extended time may add to the RT when the subject finally does glance back to the forward roadway and notices the light. Alternatively, if the light has already turned off by the time the subject glances back to the forward view, the light would be missed. The HDRT, because it is mounted on a headband that is affixed to the head, and hence moves with the head, is not affected at all by head movements. In addition, eye movements relative to the head cannot place the stimulus outside the test subject’s visual field. With the standard placement of the HDRT, even with a large eye movement relative to the head, the visual stimulus still always falls on the retina. For example, if the participant looks at the road ahead but glances to the SuRT display without moving his or her head, the HDRT light is still visible in the retinal periphery (Sean Seaman, personal communication). The effect of eye movements is therefore not as large with the HDRT as it is with the RDRT, but it still potentially exists to the extent that the peripheral retina has a different RT than the central retina. The differences in the RT responses to a DRT light in the central vs. peripheral retina are quite small, but were still found to account for about 5 % of the variability when a left or centre light was randomly activated in the same DRT experiment during 79 commonly done visual-manual tasks in five vehicles, in an experiment conducted on the VTTI Smart Road.[107]

In addition, the standard HDRT light has a higher luminance than the standard RDRT light, as well as a larger visual angle (i.e. image size on the retina) because the LED is much closer to the eyes than with the RDRT. Increased luminance and increased size of the light both increase stimulus “intensity” and thus are well known in vision science to give rise to faster RTs. In contrast, the TDRT is not subject to light falling off the retina due to eye movement effects, nor luminance and spatial summation effects, because there is no visual stimulus with the TDRT. Table E.6 summarizes these predicted effects on RT of the various DRTs from eye and head movements.

Table E.6 — Predicted effects of DRT types on RT as a function of head and eye movements

Task	Type of movement	
	Head	Eye
TDRT	No effect	No effect
HDRT	No effect	Slight increase
RDRT	Increase	Increase

E.5.2.3 Examination of RT similarities across DRT versions

The RTs for all the DRT types that involve a manual response component (as in this document) are likely increased during any secondary task that involves a manual component. Cognitive control is required to resolve response conflict between the commands issued to the motor resources that control the actuator resources (the two different hands). (See the three-level resource model in Figure A.1.) Cognitive control is required to decide whether and when to press the DRT button, vs. whether and when to press the SuRT button; see Reference [104]. Note that this is not a low-level actuator resource conflict, such as if the same hand or finger had to be used for the SuRT button and the DRT button. It is also not a mid-level motor resources conflict as in Figure A.1 because the high-level motor systems that control the left and right hands are distinct in the cortex of the brain, and the left and right arms are controlled by separate muscles. Indeed, the individual button presses for the SuRT and DRT are well-practiced and undoubtedly nearly automatic by the time the subject has had a considerable amount of practice or proceeded fairly far in the test protocol. Despite these facts, all the DRTs in this document will have RT increases if a secondary task has a manual component. The reason is because cognitive control (executive attention) is required to decide which motor command to issue to the muscles controlling the left or right hand and when to issue it. Cognitive control is required to resolve conflicts such as “should the SuRT button be pressed in the next instant or should spatial attention be kept on the DRT stimulus location?” (Even a tactile stimulus has a spatial location.) Cognitive control is also required to resolve the conflict of should the DRT button be pressed when the stimulus is perceived or should the SuRT button be pressed? Should the SuRT task being perform with more accuracy (fewer errors) or on the DRT task (misses)? Thus, although the DRT and SuRT tasks may be highly practiced and even nearly “automatic” when performed alone, when they are performed concurrently as in these experiments, they require cognitive control to choose between them and perform them quickly and avoid errors. That is, the cognitive control network shall make decisions (i.e. resolve conflicts) as to which motor command plan (left or right button press?) is to executed and when. This multiple concurrent behaviours (along with driving as well) give rise to multiple response conflicts, even for tasks that are well practiced individually. Thus, all the DRTs in this document will have increased RTs for any task that requires a manual response vs. the same task being performed with some other method of response than a manual response (or foot response). This analysis is fully consistent with the model in Annex A.

E.5.3 Answer to question 3

Question 3 asked, “Is the DRT RT *sensitive* and *specific* to the attentional effects of low vs. high levels of cognitive load for auditory-vocal and visual-manual tasks?”

For the n-Back (auditory-vocal) task, 1-Back generally has significantly longer RTs than 0-Back, all else being equal. This can be generally explained by the fact that 1-Back has a greater working memory load than 0-Back. This consistent finding strongly supports the sensitivity of the DRT RT metric for auditory-vocal tasks, regardless of DRT type.

For SuRT (visual-manual), RTs for the easy and hard condition generally does not differ. Moreover, both the easy and hard conditions generally had significantly longer RTs than the 0-Back task and similar or only slightly longer RTs than the 1-Back task. The key question here is whether the DRT RT metric specifically captures the effects of cognitive load on attention imposed for visual-manual tasks. This issue is not yet fully resolved and a number of different interpretations have been made. Some of the main lines of explanation are outlined below. These and several other explanations in the light of recent findings in cognitive neuroscience and experimental psychology are further discussed in Reference [104].

It may be suggested that the specificity of the visual DRT versions (HDRT and, in particular, RDRT) to attentional effects of cognitive load may be compromised by the fact that they could also be specifically sensitive to interference in the visual modality. If so, the finding that the Easy and Hard SuRT yielded longer RT values than the 1-Back task could be explained in terms of specific sensory/perceptual visual interference. However, this does not explain why the TDRT (which does not compete for visual resources) also found that both Easy and Hard SuRT had longer RT values to 1-Back (see grand mean TDRT in Figure E.1).

One line of explanation for the lack of difference between the Easy and Hard SuRT on DRT RT is that participants adopt certain task allocation/pacing strategies such that they tend to slow down the pace on the Hard SuRT to compensate for the difficulty while instead trying harder, and performing at higher pace, on the Easy SuRT. Thus, according to this interpretation, the resulting degree of cognitive control allocated to each task is similar, as reflected in the DRT RT.

Another possible interpretation, which does not exclude the previous one, derives from the fact that the DRT and the SuRT both rely on manual responses (button presses) separately executed with the two hands. Thus, there is a potential for motor response conflicts that need to be resolved by cognitive control. Such motor conflicts are not present to the same degree for the n-Back task since it relies on vocal rather than manual responses, which presumably would not conflict as much with the manual responses to the DRT. Analysis of SuRT button presses (e.g. in Reference [104]) showed that the Easy SuRT has a far greater number of button presses than Hard SuRT in a given trial time. Hence, there is a stronger potential for motor response conflicts with the DRT for the Easy SuRT compared with the Hard SuRT. Resolving such conflicts places a relatively strong load on cognitive control, which is reflected in longer RTs for Easy SuRT, making its cognitive load effect on attention similar in degree to that of 1-Back and Hard SuRT. Thus, even if the Hard SuRT, when performed without the DRT (alone or during normal driving), requires a higher degree of cognitive control than the Easy SuRT, the stronger response conflicts with the DRT for the Easy SuRT results in a similar attentional effect of cognitive load as the Hard SuRT when the task is performed concurrently with the DRT. Recently finished studies used different pacing regimes of SuRT in order to investigate the effect of SuRT difficulty on TDRT performance.[86][87] The results showed significant effects of SuRT difficulty on both TDRT RT and TDRT hit rate, if the Easy SuRT and the Hard SuRT did not differ in the number of button presses and the amount of response interference. As noted in Clause 1, if this interpretation is correct, it warrants some caution when interpreting DRT results from response-intensive tasks, if the goal is to separate the attentional effects of response conflicts from the attentional effects of working memory load.

However, the observation that both the visual-manual SuRT task had a longer RT than the auditory-vocal n-Back task should not be surprising on general principles because it has been well established since Young and Angell[107] that some visual-manual tasks have a strong cognitive load component associated with DRT RT and miss rate metrics, distinct and separate from their physical load component associated with task time, eyes off road time and subjective workload. Indeed, the CAMP-DWM study found that visual-manual tasks increase RT and miss rate in an experimental open-road or closed-road setting more so than auditory-vocal tasks (see References [6], [114] and [115]). The CAMP-DWM visual-manual tasks were also re-analysed using the same dimensional analysis as in Reference [107], and some visual-manual tasks were verified to have a strong cognitive load component.[112] The cognitive load component of visual-manual tasks was also explicitly recognized by a team of experts in a key paper concerning the fundamental definition of driver distraction in Reference [34].

Further studies are needed to shed more light on the sensitivity and specificity of the DRT RT measure to the attentional effects of cognitive load for visual-manual tasks.

E.6 Analysis of hits and misses in ISO DRT cross-site studies (question 4)

Question 4 was, “To what extent are the results for hits/misses consistent with those for RTs?” To answer this question, some background understanding of hits and misses is first required.

E.6.1 Definition of hit and miss

The results in this section are mainly discussed in terms of misses rather than hits. As specified in the main body of this document, a miss is defined as the complement of a hit and the miss rate is thus the hit rate subtracted from 1.

E.6.2 What does a *miss* mean in the context of the DRT?

A miss means that “task load” interfered with the ability to attend and respond to the DRT stimulus at a given moment. The nature of the interference is perhaps different in magnitude from a slowed response time. A slowed response time indicates that attentional processes are slowed in responding to DRT stimuli. Misses, however, may also indicate that the attentional processes have “failed”, in the sense that no detection/response to a stimulus occurred at all within the defined period.

Of course, it could be argued that a miss may just be an extreme slowing of response rather than a total miss of the stimulus (i.e. there really would be a response if a longer time than 2 500 ms were allowed). However, fine-grained analyses extending the window of analysis beyond the cut-off point of 2 500 ms have found little or no evidence that misses represent “extreme slowing” in which a response would eventually occur, if only enough time were allowed for the response.

E.6.3 Multiple causes of misses

The misses of main interest in the scope of this document are those caused by the attentional effects of “cognitive load”, rather than those caused by “visual load” from a secondary task. However, some misses may also result from effects of “visual load”, as described below.

E.6.3.1 Not “seeing” a DRT stimulus

If the visual load of a secondary task leads a driver’s eyes to be positioned at a visual angle that is too large compared with the position of DRT stimuli (e.g. near the forward line of sight to the road), it is obvious that these DRT stimuli will be missed (e.g. as in a remote visual DRT) because the events do not fall on the retina. The metrics for measuring eyes-off-road time and other glance metrics are well established in the driving literature. Such metrics have been used to capture the “glance portion” of a secondary task’s visual load and have been shown to be safety-relevant in naturalistic driving studies.

E.6.3.2 Not “shifting attention”

RTs and misses will be reduced (i.e. improved) if attention is shifted to the location that needs to be monitored for DRT stimuli. Not all of the variance in missing a DRT stimulus under visual task load is accounted for by extreme visual eccentricity; some of the variance is apparently caused by failures to shift attention to a stimulus location that needs to be monitored, independently of eye movements, an effect which has been well studied in cognitive psychology.[75] This is an *attentional effect* of secondary task loading.

Whether it is attributed to a task’s *visual load*, or attributed to the attentional effect of a *cognitive load* (i.e. a failure of cognitive control), matters less than the fact that it contributes to “misses”. A driver who looks away from the location of DRT stimuli can miss a visual DRT stimulus because of a) visual task load that leads to the DRT events not falling on the retina, b) the attentional effects of cognitive load or c) shedding the DRT, or some combination of these. Nonetheless, effects of “visual secondary task load” are not the central interest of the main body of this document.

E.6.4 DRT types and misses

It is, however, important to be aware that different types of DRTs are differentially sensitive to the contributing “causes” of misses.

— The RDRT is sensitive to the effects of both visual load and the attentional effects of cognitive load.

— The HDRT is sensitive to the attentional effects of cognitive load and reduces the effects of visual load (relative to the RDRT) by mounting the light stimulus on a headband that moves with the head.

NOTE The measures can still be somewhat affected by factors related to visual load.

— The TDRT is mainly sensitive to the attentional effects of cognitive load, at least if non-tactile secondary tasks are being assessed. Since the main tactile stimulus is not a visual stimulus, it can act as a “probe” for the central attentional effects arising from the cognitive load of visual-manual tasks.

  — The TDRT RT and hit/miss rate are not expected to be affected that much by visual load.

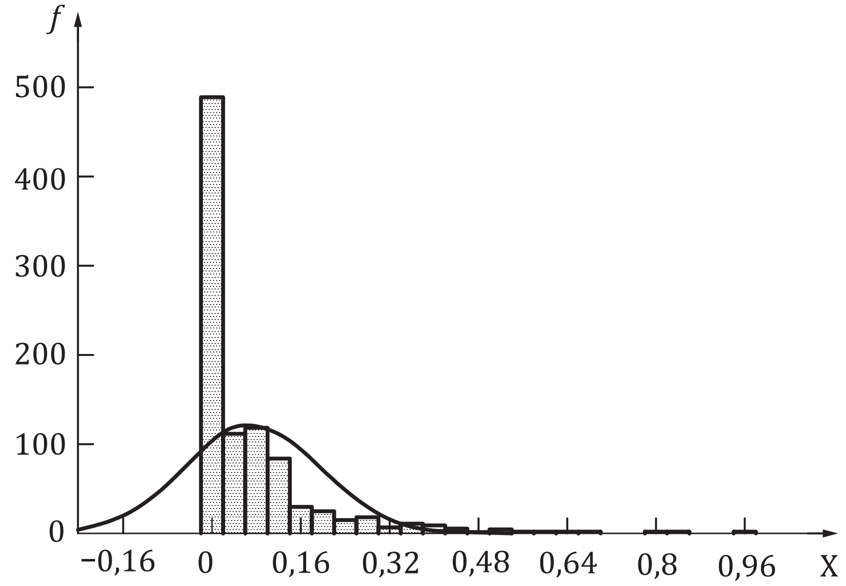
  — They are expected to be affected by the effects on attention of cognitive load.

  — The hypothesis is that the hit/miss rate (or RT) to a tactile stimulus will be affected in the same manner as the hit/miss rate or RT to a visual or auditory stimulus because the central attention effects of orienting to those stimuli are similar regardless of sensory modality.

  — By studying the effect of a secondary task on the miss rate (or RT) to a tactile stimulus, we are assumed to be estimating the effect of a secondary task on the miss rate (or RT) to a visual stimulus, independently of any eye movements or blinks.

E.6.5 Miss rate analysis methods

Figure E.6 shows all the 945 miss rates (i.e. the probability of a miss) for all sites, DRTs, tasks and participants in the main cross-site study of the four sites which provided complete data. Visual inspection of Figure E.6 shows that there is a dominant peak in the miss rate at 0 (no misses), with a long tail to the right, out to almost 0,96, meaning that one subject for one test condition missed almost every DRT stimulus. The results for hit rate (not shown) are exactly the complement, a dominant peak at 1 (all hits), with a long tail to the left.



Mean	0,072 54
StDev	0,124 4
N	945

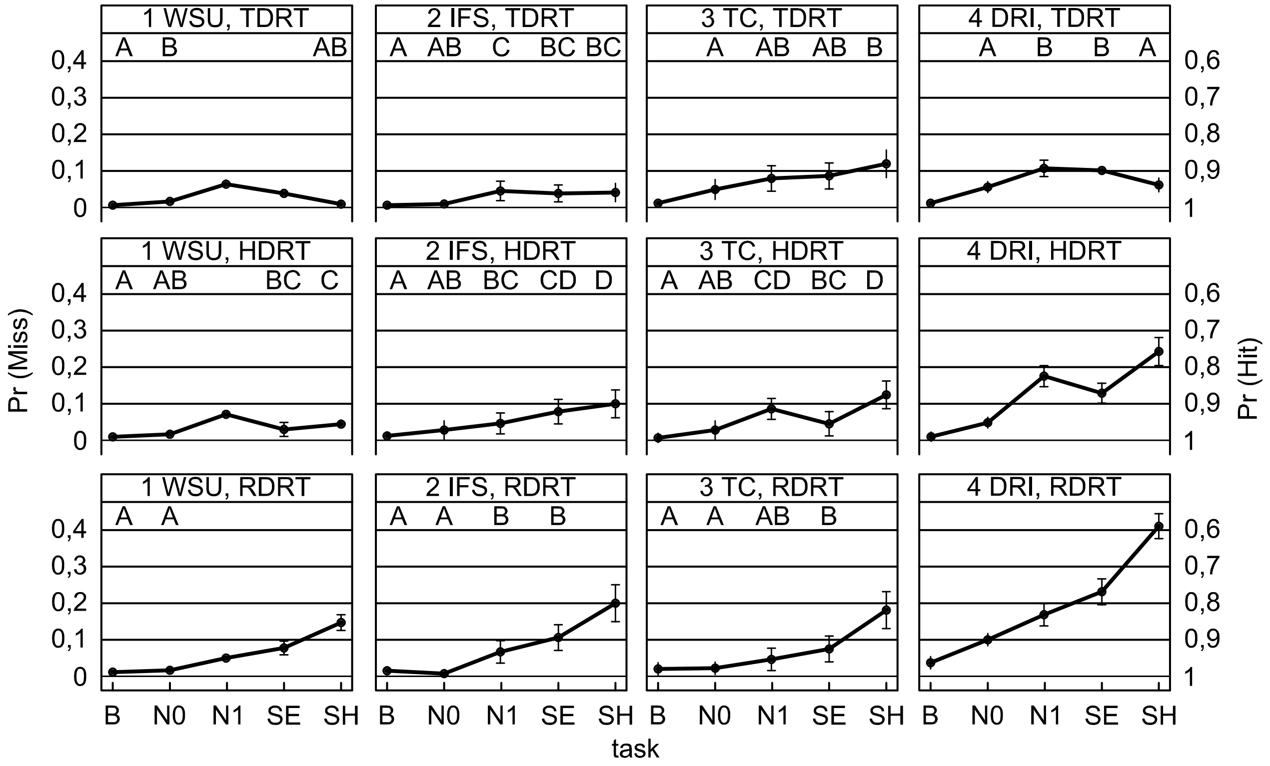
Figure E.6 — Histogram showing statistical distribution of 945 miss rates in the main study compared with a normal distribution

The best-fit Gaussian distribution shown as the blue line in Figure E.6 is a poor fit because the data are extremely non-Gaussian. This extreme non-normality indicates that conventional statistics applied to hit/miss rate data will not give rise to valid estimates of the population. Even the calculation of a mean, standard deviations, standard errors, etc., from such a non-parametric sample will not be correct when extrapolated to the population. Hence, conventional statistics (e.g. ANOVA) will not give valid estimates of the population if applied to such extremely non-normal distributions. Standard deviations, standard errors and variances in general will be too large with a distribution like that in Figure E.6 because they assume an underlying Gaussian distribution. The distribution in Figure E.6 is so extreme that there is no reasonable transformation of the data that will convert it to a normal distribution. The basic reason is that hits and misses are binary and not continuous variables.

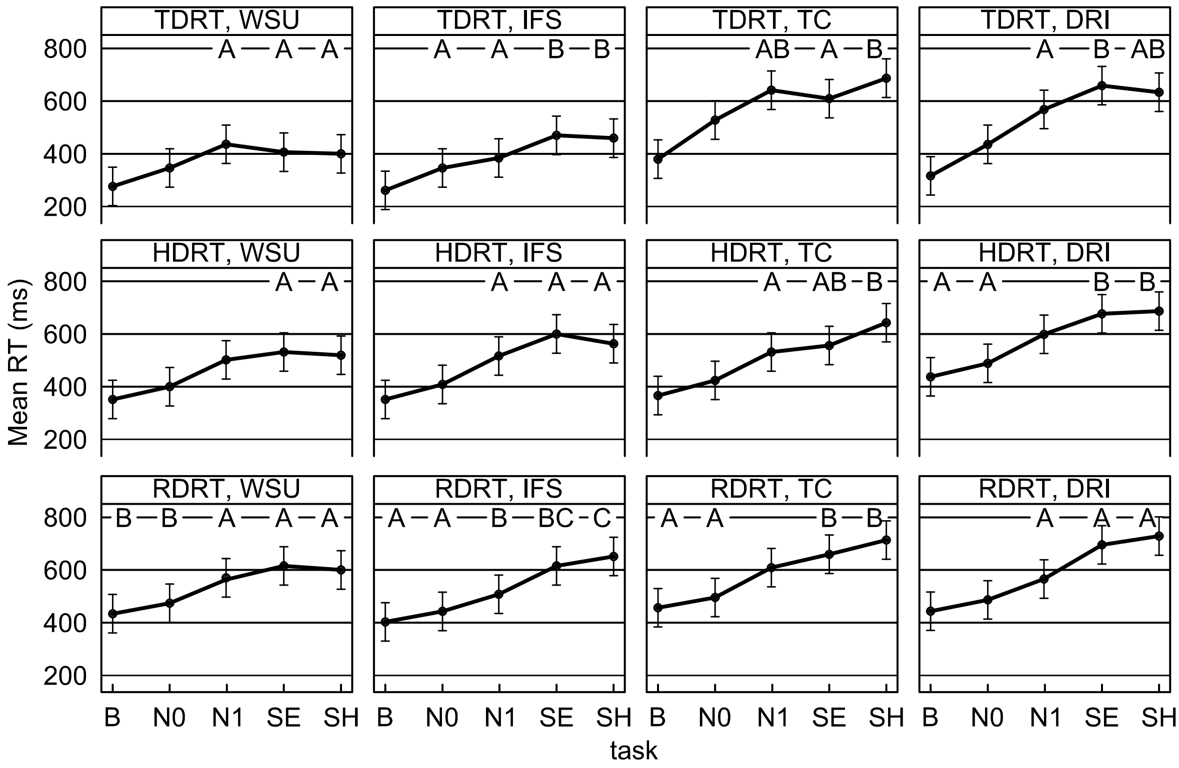
A more appropriate method of analysis is therefore logistical regression analysis. A logistic regression analysis was performed, which assumes only binary responses (a hit or miss). No normality assumption is required. The method was applied to the individual hits and misses on a stimulus level. That is, the hits and misses for each individual subject are tabulated and analysed. Hence, there is a much larger *n* (the number of events) compared with when using conventional statistics, which have the *n* as the number of participants. There is a corresponding large increase in statistical power using logistic analysis. That is, confidence intervals are much smaller than with ANOVA and the ability to discriminate between task conditions is much better than with an ANOVA. The results for the four sites with complete data are redrawn in Figure E.7. These results may be compared with those for the RT in Figure E.1.

E.6.6 Miss rate results

Figure E.7 a) shows the results of the logistic analysis for the four main sites with complete data. Figure E.7 b) shows the reaction time results from the four main sites redrawn from Figures E.1, E.2 and E.3. The confidence intervals are generally smaller for the misses/hits than for the RT. Analysing the patterns in the changes in the probability of a miss across the tasks for each DRT type reveals several new findings not seen in the RT metric.



a) Data used in the logistic regression plotted as hits and misses from the four main sites



b) Reaction time data for comparison from the four main sites (redrawn from Figures E.1, E.2 and E.3)

Key

B baseline

N0 0-Back

N1 1-Back

SE SuRT Easy

SH SuRT Hard

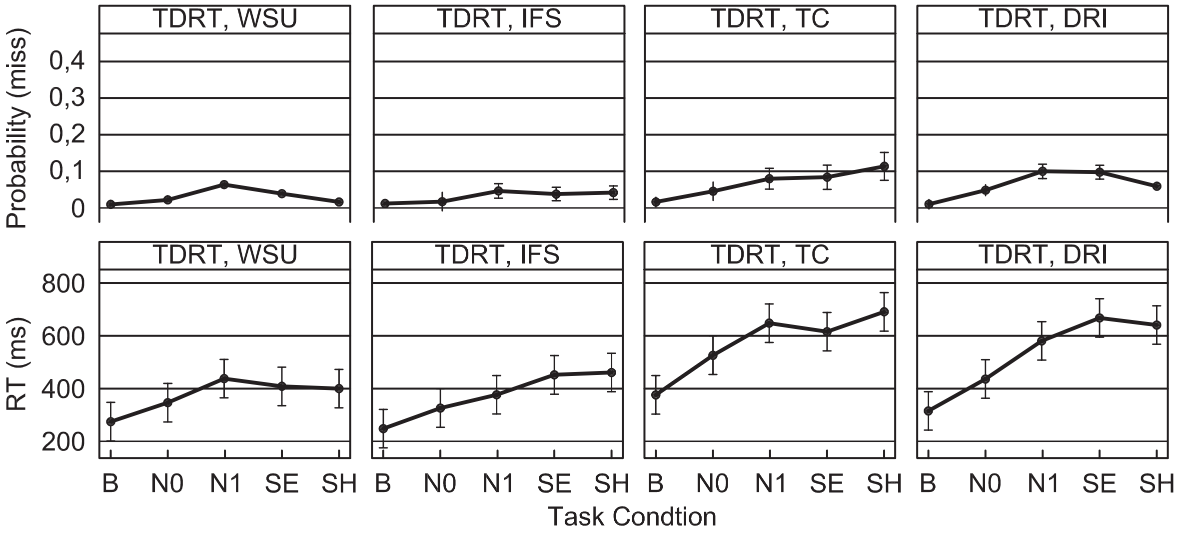
Figure E.7 — Miss rate and reaction time data for the four main sites with complete data

The error bars are 95 % confidence intervals. The task conditions are shown on the *x*-axis. Task conditions sharing a letter label within each site and setup are not significantly different at the $p = 0,05$ level. Figure E.7 a) plots the probability of a miss or hit as function of the task condition for the main four sites with complete data. The left *y*-axis shows the probability of a miss. The right *y*-axis shows the complementary probability of a hit. Figure E.7 b) shows the same as Figure E.7 a) but with RT on the *y*-axis.

E.6.6.1 TDRT: Hard SuRT had no significant difference in misses vs. Easy SuRT

The following figures redraw the results from Figure E.7 for an easy visual comparison of miss and RT metrics.

Figure E.8 shows that for TDRT, Hard SuRT and Easy SuRT had no significant differences in misses for all four sites consistent with no significant differences in their mean RTs.



Key

B baseline

N0 0-Back

N1 1-Back

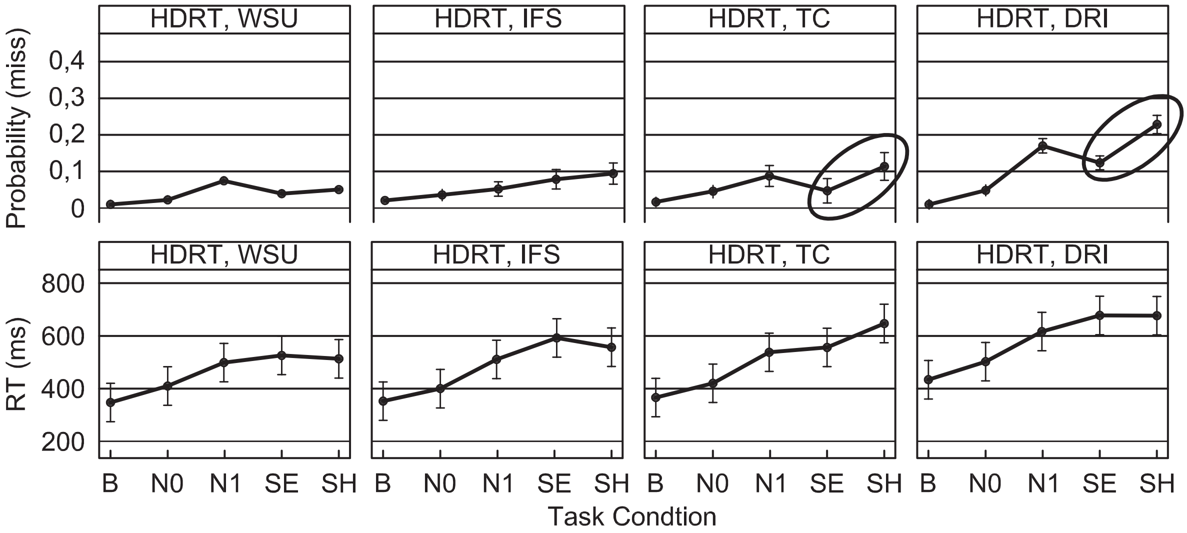
SE SuRT Easy

SH SuRT Hard

Figure E.8 — TDRT results redrawn from Figure E.7 for comparison of miss and reaction time metrics

E.6.6.2 HDRT: Hard SuRT has more misses than Easy SuRT, but RTs were not different

Figure E.9 (top panel) shows that for HDRT, Hard SuRT had more misses than Easy SuRT for site 3 (TC simulator) and site 4 (DRI on-road) (black ovals). The mean RTs (bottom panel) for Hard SuRT and Easy SuRT were not statistically different.



Key

B baseline

N0 0-Back

N1 1-Back

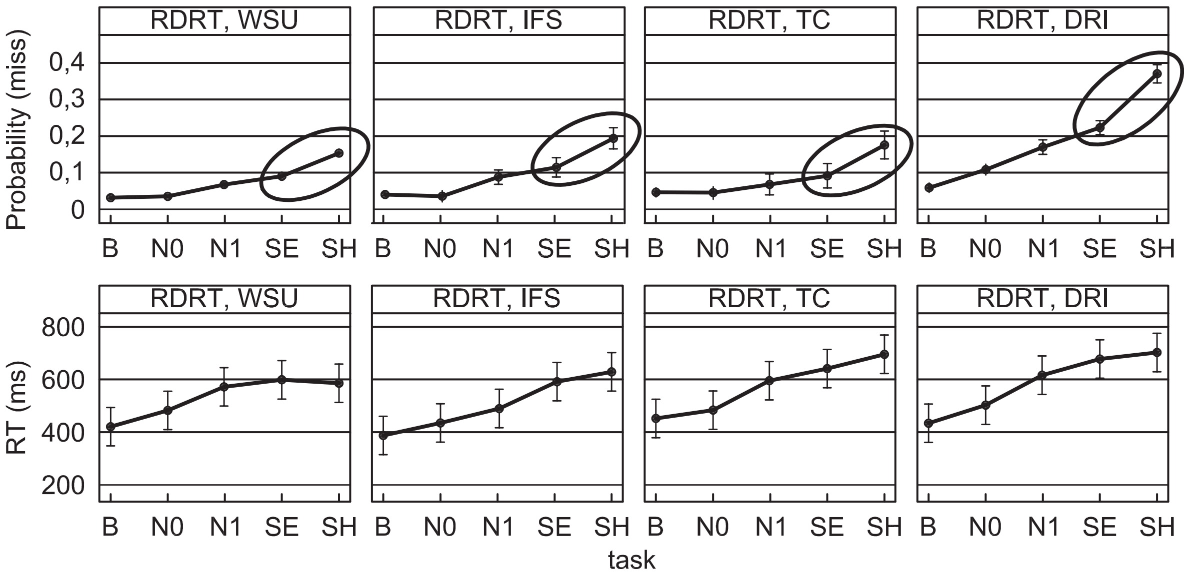
SE SuRT Easy

SH SuRT Hard

Figure E.9 — HDRT results redrawn from Figure E.7 for comparison of miss and reaction time metrics

E.6.6.3 RDRT: Hard SuRT has more misses than Easy SuRT, but RTs were not different

Figure E.10 shows for RDRT as with HDRT in Figure E.9 that Hard SuRT had more misses than Easy SuRT for sites TC and DRT, but now also for WSU and IFSTTAR (top panel, black ovals). The DRI road setup (upper right) has particularly large increase in the miss rate for Hard SuRT vs. Easy SuRT. Yet, the mean RTs for Easy and Hard SuRT (bottom panel) were not statistically different.



Key

B baseline

N0 0-Back

N1 1-Back

SE SuRT Easy

SH SuRT Hard

Figure E.10 — RDRT results redrawn from Figure E.7 for comparison of miss and reaction time metrics

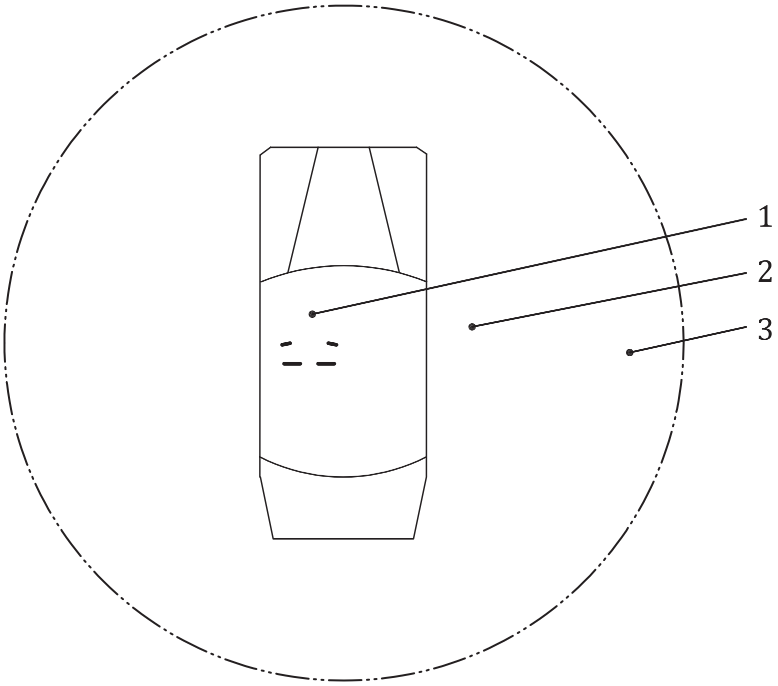
E.6.7 Discussion, miss analysis

The key finding from this miss analysis was that the probability of a miss for the visual DRTs, in particular the RDRT, exhibited a stronger sensitivity to the Hard SuRT than to the Easy SuRT. This contrasts sharply to the results for RT, where none of the three DRT versions distinguished between Easy and Hard SuRT. For example, the TDRT miss probability was similar for Easy and Hard SuRT and generally lower than for the visual DRTs. It could also be observed that the n-Back task had a relatively minor effect on DRT miss probability in general.

There are several possible interpretations of these results. First, the finding that the effect of SuRT task level only occurred for the visual DRTs, and not for the TDRT, may indicate that the effect was due to a specific interference in the visual modality. The further result that the effect was stronger for the RDRT than for the HDRT might indicate that the effect was mainly due to visual sensory, rather than visual perceptual, interference (that is competition for the eye rather than competition for visual perceptual resources in the brain; see Annex A for the definition of these terms). The reason is that, as explained above, the RDRT stimulus, during glances towards the SuRT display, might appear in the visual periphery or even outside the field of view. Since the HDRT stimulus is fixed to the head, this effect is reduced compared with the RDRT for those participants who tend to make head movements rather than eye movements to view and respond to the SuRT device. Hence, the high miss rate observed for the Hard SuRT might be mainly related to eye movements towards the display increasing the visual eccentricity of the DRT stimulus. Under this interpretation, the effect of SuRT on miss rate is not at all related to attentional effects of cognitive load but rather to the physical incompatibility between the display and the DRT stimulus locations. This can be further investigated by a more detailed analysis of eye movements in relation to DRT stimulus timing. A further finding was that the comparison of 1-Back to 0-Back (which can be regarded as a pure cognitive difference) did not appear to have any strong effect on DRT miss rate. However, the fact that the difference between Easy and Hard SuRT was also found for HDRT (at least for some sites) indicates that visual perceptual interference might play a role as well or that some participants may make eye movements rather than head movements to interact with the SuRT.

An alternative (but related) interpretation is that participants might occasionally completely shed the visual RDRT and to a lesser extent the HDRT (increasing their miss rate), in order to maintain good performance on Hard SuRT, in a classic speed-accuracy trade-off. However, since the TDRT does not compete for visual resources, it is not shed to the same extent by the participants. Likewise, visual DRTs may not be shed when they are combined with the n-Back task. In short, this interpretation says that some stimuli were completely ignored to keep the RT at an acceptable level. Whether the "ignoring" of the stimuli was a conscious decision on the part of the subject, or was rather caused by an effect of the attentional load of the SuRT tasks that was not a conscious process of the participants, will require further research investigation.

For example, it has also been suggested[104] that the increased misses of RDRT and HDRT for Hard SuRT reflect a true attentional effect from increased cognitive load of the Hard SuRT. Under this interpretation, the high miss rate for the Hard SuRT reflects a cognitive control (or attentional) failure to shift attention to this stimulus location (rather than gaze being directed in the wrong direction). If so, the observed elevation in miss rates for HDRT and RDRT reflect the true attentional effects of the Hard SURT. Apparently speaking against this hypothesis is the finding that the TDRT miss rate appeared insensitive to SuRT level. One possible explanation could be that the TDRT is on the body (personal space) and so has much greater stimulus salience than a stimulus that is off the body (extrapersonal space) (see Figure E.11). However, this still seems to leave open the further question why the 1-Back task does not increase the RDRT/HDRT miss rate more than it does (while it does have a strong effect on RT).



Key

1 personal space

2 peripersonal space

3 extrapersonal space

NOTE Adapted from Reference [41], Figure 8.1, p. 94.

Figure E.11 — Schematic diagram of the concept of the different functional regions of space around the driver

Thus, in answer to question 4, "To what extent are the results for hits/misses consistent with those for RTs?" the current cross-site analysis clearly shows that hits and misses reveal information above and beyond that found with RTs. The simplest interpretation that fits the present data seems to be that miss rate for the visual DRTs is sensitive to specific visual interference (sensory and to some extent perceptual). This would imply that the specificity to attentional effects of cognitive load is highest for the TDRT, while in particular the RDRT might be useful for capturing other effects of secondary tasks, e.g. effects of display position (see Annex E), or detecting events that are not in the forward view of the driver. However, as outlined above, alternative interpretations are also possible so further empirical work is clearly needed to decide between these different interpretations.

E.6.7.1 Discussion of the benefits of miss[7)] analysis from different perspectives

E.6.7.1.1 Measurement

Misses may carry important information in their own right (in addition to response times). In addition, misses may carry information about when the loading of a task is so high that it interferes to an extreme degree with attentional processes that not only slow stimulus responses down, but also lead to missed events altogether.

E.6.7.1.2 Experimental control

Many classical experimental psychology studies historically used miss rate simply as a control variable for response time (RT). For example, miss rate is often used to ensure that participants are not making a speed-accuracy trade off (e.g. such as described by Fitts's law). An early draft of this document employed hit rate in this manner, using a criterion hit rate of 80 % simply to make sure that there were sufficient RTs to ensure a stable measurement. Therefore, an examination of hit/miss rate for different tasks is important because participants can, for example, trade off accuracy (i.e. have fewer hits or more misses) in a visually difficult task (e.g. Hard SuRT), in order to keep their RTs low. In other words, two tasks could (erroneously) appear to have the same attentional effects from cognitive load if just RT were examined, but may have different attentional effects if hit/miss rate is analysed. Hit/miss rates may thus provide additional information that is not available from RTs alone. Indeed, participants had more misses during Hard SuRT than Easy SuRT for HDRT (Figure E.9) and RDRT (Figure E.10), and this result was not seen in the RTs. In other words, although the RTs are the same across the sites for Easy and Hard SuRT for each of the DRTs, the miss rates are not. For these and other reasons, a deeper examination of misses seems warranted.

E.6.7.1.3 Safety

On the roadway, it has been suggested that conditions under which safety-critical visual events can be missed during driving – when the eyes are open and on the road (and sleepiness is not present). For example, there may be conditions under which the driver is either under a task load that is endogenous (e.g. cognitively processing internal thoughts) or exogenous (e.g. processing information from an in-vehicle information system or from roadway signs about a detour), wherein the task loading is high enough that it interferes with the driver's ability to respond to new events. If so, and a new event occurs on the road ahead, is it possible that the new event be missed even though the driver is looking directly at it with eyes open? This question is related to the questions that the DRT is supposed to address. Misses may therefore be the main aspect that makes the DRT safety relevant, even more so than RTs. The question to be investigated in future research is: With the eyes open and on the road with a normal non-drowsy driver,[8),9)] can safety-critical visual events be missed during driving from the attentional effects of cognitive load arising from a secondary task?

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7) These perspectives may equivalently be viewed in terms of hits, the binary complement of a misses, but the discussion is easier to follow in terms of misses.

8) It is assumed that the driver is not drowsy or experiencing micro-sleep episodes as evidenced by alpha spindles. Alpha spindles are a more sensitive measure than the traditional alpha band power for drowsy driving.[89]

9) It has also been reported that when attending to a location, other locations that might have targets show increased alpha. Such localized alpha is evidence of inhibition at the unattended location, not evidence of going to sleep.[101]

The following are some relevant examples of tasks that have been suggested as causing such attentional effects from cognitive load:

— visual-manual tasks with a high cognitive load (e.g. CAMP-DWM HVAC task);

— an auditory-vocal task (e.g. cell phone conversation);

— an external visual stimulus (e.g. billboard advertisement);

— internal random thoughts (not an observable secondary task).

Given such a task, assume that a new event occurs on the road ahead (e.g. forward vehicle activates its brake lights, a stop light turns red, etc.). Can that event be missed because of the attentional effects of cognitive load from such tasks?

Misses may be as safety-relevant (or more safety-relevant) than response time (RT) in assessing the attentional effects of cognitive load. An increase of a few hundred milliseconds in RT while driving has not been proven to increase the risk for a normal driver who self-regulates. That is the same duration as an eye blink, which happens all the time during driving. Drivers can and do easily compensate for such small increases in RT via self-regulation (e.g. as shown during auditory-vocal-cognitive tasks such as cell phone conversation[114][115]).

A *miss,* however, is defined in the main body of this document as a stimulus to which there is no response within 2 500 ms and 2 500 ms may be outside the RT range in which a normal driver can successfully self-regulate their driving to fully compensate.[114][115] Indeed, response delays of more than 2 500 ms are well established in the driving safety literature to be associated with an increased crash risk.

E.6.7.2 Future work on signal detection theory and hits/misses

Because the stimuli in the DRT protocols are all far above sensory threshold, the usual assumptions made for signal detection theory are not met. ROC curves, d-prime or any of the other signal detection metrics and methods are not designed for supra-threshold signals. However, the data examined here show that even supra-threshold events can be missed because of attentional effects. Therefore, signal detection methods may be appropriate, if re-framed within the context of attentional effects.

The psychology literature has examples of signal detection theory used for tasks not involving thresholds: event detection as affected by attention (e.g. the “attentional blink”) and memory tasks. One has to be careful in these cases not to see d-prime as purely sensory, it may involve attention for example. The analysis of sensitivity and specificity for medical screening tests is also closely related to this work and is applied to supra-threshold effects all the time. Applying this requires additional research that has not previously applied to miss rate data in a driving safety context.

E.6.8 Conclusion to hits/misses

In conclusion, even though hits and misses are highly correlated with RTs in studies using the DRT with secondary tasks[107][112], the current cross-site analysis shows that hits and misses have the benefit of revealing information above and beyond that found with RTs. DRT hits and misses therefore enhance the understanding and importance of attention while driving.

E.7 General discussion

E.7.1 Advantages of DRT

There are numerous advantages to the DRT method as presented in this document and assessed in these coordinated studies. The laboratory DRT does not require expensive resources to conduct, as do on-road tests, and yet it produces the same relative results. The DRT method presents multiple stimuli for detection over a period of time to assess the effects of cognitive load. This is in contrast to object and event detection methods that usually present only a single stimulus.[96]

In addition, the DRT can be applied for improving human-vehicle interface designs with only an early functioning prototype of that interface. Finally, the ISO DRT procedure is sufficiently repeatable across sites, and sufficiently stable in repeated tests at a given site, that it is suitable for final acceptance testing for assessing the attentional effects of cognitive load in production applications.

The methods of analysis developed and applied to the study of missed events may also be of benefit in improving methods of analysing crash data. As shown in Figure E.6, misses are rare events, with a non-Gaussian distribution with a long tail on the right side. They thus have the same non-parametric distribution as crashes (crashes are also rare events, with a long tail in the right-hand distribution). The vast majority of the time a person drives, there is no crash. A deeper understanding of the ways to analyse the misses of events, such as those in the detection-response task, may thus inform better ways to analyse crash data.

E.7.2 Limitations and cautions with DRT

E.7.2.1 Crash risk and attentional effects of cognitive load

The results presented in this annex show that the RT and hit/miss rate metrics used by the DRT allow for a meaningful differentiation between the tasks tested in terms of the attentional effects of their cognitive load. Indeed, the relative ranking of tasks is consistent between many different setups (non-driving, surrogate, simulator or road) and across all eight sites.

However, the cross-site experiments examined here are not sufficient to either prove or disprove whether the effects on attention as measured by the DRT have any role (or not) in causing crashes in real-world driving. Methods to establish a connection between the attentional effects of cognitive load and crash risk will require a) a valid estimate of crash risk, b) a valid measure of the attentional effects of cognitive load and c) a new way to connect a) and b) in naturalistic driving data. This has not been done in any published study to date. Conjectures about crash risk and cognitive load effects are purely speculative until that is accomplished.

E.7.2.2 Setting acceptance criteria

It is not within the scope of this document to set acceptance criteria based on RT or hit/miss rate. The intention of this document is to provide a specification of the DRT itself and this cross-site study was undertaken to show that DRT results are valid and consistent when measured at many different sites, lending credence to the intrinsic validity of the DRT method. However, these results show conclusively that setting an absolute criterion for RT or hit/miss rate will not work. The absolute values of RT and hit/miss rate vary considerably between eight highly experienced laboratories in many different countries, using similar or identical DRT methods and DRT devices. Any attempt to set an absolute criterion will therefore lead to major differences between sites. A product that is tested against an absolute criterion could meet or not meet the criterion just depending upon where it is tested and what DRT is used to test it, irrespective of whether the task is safe to do while driving or not.

However, the relative relationship between the tasks is highly consistent across sites and DRT types. Therefore, these data provide a strong indication that any acceptance criteria should be based on a relative criterion, not an absolute one. For example, a ratio or a difference score from baseline would provide such a relative ranking. The sensitivity and specificity of such a relative ranking method should be examined in future research, but it is outside the scope of this document to prescribe a particular way to make such a relative criterion.

E.7.2.3 Cautions on use of short exposure times or single trials

Exposure time is the product of trial time and the number of trials. Longer exposure times require a longer total experimental time for each subject and so require more experimenter time to conduct the test. However, longer exposure times have the benefit of allowing more stimuli and responses to be collected for each task condition for each subject, giving rise to smaller uncertainty ranges. In addition, the greater number of responses that are averaged for each task helps to "even out" the occasional long outlier RT that occurs randomly because of factors such as an eye blink or the occasional memory lapse in recalling the next step in the series of steps that constitute a task.

E.7.2.4 More tasks needed

Only two levels of two task types were investigated in this cross-site validation project. These methods should be extended to many more tasks. The n-Back task is an invented non-ecological task that is not actually performed in vehicles and likewise for SuRT. However, 79 visual-manual tasks commonly performed in vehicles have been investigated in an experimental study on a closed road with five vehicles and a large number of participants.[5][107] Their analysis of that data clearly show that the DRT is an effective measure that can discriminate the attentional effects of cognitive load from the physical load of secondary tasks commonly performed in a vehicle. This conclusion was confirmed in a similar analysis[112] of 13 visual-manual tasks in the CAMP-DWM data set.[6] Therefore, it is likely that the results and conclusions of this cross-site study will be further validated when larger visual-manual task data sets are considered. The use of the DRT methods in a composite data set that includes both visual-manual and auditory-vocal tasks would benefit from further investigation. Visual-manual and auditory-vocal tasks have fundamentally different properties, and the usual metrics of, for example, eyes-off-road time, task time, standard deviation of lane position, etc., cannot discriminate the cognitive load effects on attention of auditory-vocal tasks, nor of visual-manual tasks for that matter, as shown in References [107] and [112]. Therefore, it is essential that the DRT methods, which this cross-site study has shown can successfully measure the effects of cognitive load on attention, be implemented in addition to conventional eye glance or other driver performance metrics to achieve a more complete picture of the effects of secondary tasks while driving.

E.8 General conclusions to ISO-coordinated studies

The DRT non-driving, surrogate, simulator and road setups as specified by this document are predictive of each other in a relative but not absolute sense, when comparing data using the same tasks and the same DRT methods.

The three DRT types as specified in the main body of this document give rise to similar relative results for the RT metric. The results clearly demonstrate the sensitivity of the DRT RT metric to the attentional effects of cognitive load for auditory-vocal tasks. The results for the visual-manual SuRT task studied here are more complicated than the simple effects noted for the auditory-vocal n-Back task.

It is possible that the visual DRTs are sensitive to other effects beyond those related to cognitive load, in particular related to visual sensory interference, and/or the eccentricity of an external event relative to the forward view of the driver. Alternatively, the response conflicts between the manual responses to the SuRT and the manual responses to the DRT may be accentuated with the visual DRTs relative to the tactile DRT, and then the DRT would be accurately measuring the attentional effects of the cognitive load introduced by the manual component of a secondary task, when it interfaces with the manual load of another task (such as steering a vehicle). Further research is clearly needed to obtain a better understanding of how to interpret DRT hit/miss rate. Based on the present analysis, some initial guidelines for how to choose a particular DRT type (TDRT, HDRT or RDRT) for a given research application are given in Annex B.

This coordinated research study by the international coalition of ISO DRT team members has validated the DRT methods in a cross-site study that assessed the effects of cognitive load on attention for the set of auditory-vocal and visual-manual tasks tested, in a way that successfully predicted the relative RT and hit/miss rate effects observed in similar DRT experiments conducted at other sites and other setups, including on the open road. Additional research is needed to estimate whether and to what extent real-world crashes may be caused or prevented by the attentional effects of secondary tasks as measured by the DRT in an experimental setting.

E.9 RT data

E.9.1 RT participant-level data for main sites

Table E.7 — Mean RT for each participant by site, DRT and task for the four main sites that tested all three DRT types and provided participant-level data

No.	TDRT					HDRT					RDRT				
	B	N0	N1	SE	SH	B	N0	N1	SE	SH	B	N0	N1	SE	SH
1. WSU (Surrogate)															
1	253,1	286,6	493,6	369,9	284,8	393,2	457,2	649,5	556,5	564,2	493,0	581,0	711,5	698,2	681,0
2	214,3	294,2	289,8	349,4	335,1	295,4	349,3	373,4	503,8	434,4	347,2	422,8	491,0	515,1	533,7
3	304,0	552,2	767,9	559,8	589,1	362,9	492,8	546,8	599,8	465,0	455,0	487,0	556,5	583,8	571,5
4	254,0	386,7	363,6	337,2	358,3	402,4	427,9	640,4	467,0	618,4	353,6	393,4	456,3	417,6	447,3
5	268,8	361,8	423,6	413,0	376,5	321,7	410,8	404,6	518,0	513,7	397,6	450,7	459,3	575,7	623,1
6	238,0	406,6	454,6	455,1	445,4	290,9	397,1	489,4	679,7	608,4	405,3	468,5	487,7	768,8	703,3
7	387,5	555,1	723,2	673,8	621,6	568,5	650,2	681,1	793,1	799,0	589,1	699,8	701,0	782,0	819,7
8	173,0	189,3	226,2	249,6	180,6	274,2	328,4	359,2	464,7	424,1	356,5	377,5	543,7	563,5	599,6
9	228,4	232,2	269,9	320,1	271,7	337,8	313,6	404,6	475,0	482,4	413,3	428,5	448,5	631,4	592,5
10	223,5	284,9	428,2	353,5	346,5	301,8	321,6	437,2	460,9	420,5	376,0	376,8	468,5	638,5	704,2
11	225,4	244,0	275,6	372,9	346,9	385,8	439,4	615,8	400,4	392,1	483,7	456,6	554,6	503,5	478,0
12	330,1	441,4	595,1	493,5	518,8	349,2	456,2	548,1	517,3	601,3	482,4	509,3	605,0	732,5	733,7
13	578,9	397,7	612,9	492,2	773,6	442,3	426,1	481,8	572,8	503,0	444,0	501,4	731,0	477,8	460,7
14	293,4	317,0	458,4	430,1	402,4	475,4	467,1	752,5	697,7	762,4	544,4	605,4	926,8	976,7	698,2
15	182,4	221,6	223,9	277,4	248,8	248,2	323,4	347,4	428,0	413,0	372,9	423,7	408,3	481,8	455,7
16	298,6	382,1	382,3	400,7	403,0	343,1	415,1	503,3	501,5	446,1	568,5	570,7	643,4	590,1	587,4
Mean	278,3	347,1	436,8	409,3	406,4	362,0	417,3	514,7	539,8	528,0	442,6	484,6	574,6	621,1	605,6
2. IFSTTAR (Simulator)															
17	266,5	338,5	309,5	528,4	595,4	383,9	441,9	487,4	586,9	462,7	461,5	417,8	551,8	708,8	633,8
18	218,3	356,3	697,1	625,4	751,6	362,9	475,2	662,7	699,1	810,5	398,4	455,2	486,3	836,8	1 169,7
19	247,2	289,7	340,4	319,9	302,6	325,8	362,8	381,0	732,4	418,6	360,8	358,9	360,4	473,9	413,4
20	218,0	263,6	235,1	338,0	327,9	361,8	311,0	513,1	552,7	491,9	349,6	509,6	401,7	492,7	451,2
21	225,6	232,6	213,9	327,9	268,8	379,9	361,6	537,8	620,6	575,8	371,9	551,9	388,9	608,9	617,1
22	317,3	333,8	334,2	373,9	410,4	502,4	471,6	667,8	541,5	575,8	452,2	594,9	404,6	540,6	642,1
23	267,9	291,5	286,3	477,8	420,3	316,5	456,8	503,5	499,2	508,7	352,7	429,2	645,2	548,8	557,9
24	298,6	560,1	442,9	699,3	1021	264,3	295,1	419,0	565,6	520,9	308,8	328,1	523,9	638,8	746,8
25	239,2	347,7	468,3	530,0	377,9	318,9	369,3	550,2	527,4	627,3	348,6	380,7	507,9	692,2	656,1
26	255,5	343,3	314,3	393,3	366,0	294,9	324,5	317,5	429,3	408,6	305,4	321,7	409,9	473,9	403,9
27	237,0	343,1	354,9	444,3	347,9	360,0	515,2	859,6	843,5	578,8	375,3	517,8	630,1	741,3	727,7
28	246,0	298,3	604,3	428,1	305,5	394,7	392,7	442,3	689,8	552,8	420,7	435,8	628,8	694,3	651,8
29	231,3	319,6	329,9	459,4	454,2	393,4	520,5	606,0	502,2	689,2	523,1	424,1	468,7	845,4	740,5
30	369,2	623,7	508,1	678,4	548,1	368,5	418,4	423,5	602,5	586,9	472,6	533,4	562,5	633,7	688,5
31	308,6	305,3	404,8	533,6	407,7	428,4	582,0	528,2	666,9	738,0	610,2	519,3	654,1	567,9	835,4
32	233,5	279,4	354,4	383,2	481,2	352,4	396,0	633,9	676,8	644,1	419,1	417,6	551,2	405,1	566,2
Mean	261,2	345,4	387,4	471,3	461,6	363,0	418,4	533,3	608,5	574,4	408,2	449,7	511,0	618,9	656,4

Table E.7 *(continued)*

No.	TDRT					HDRT					RDRT				
	B	N0	N1	SE	SH	B	N0	N1	SE	SH	B	N0	N1	SE	SH
3. TC (Simulator)															
33	297,4	618,8	531,7	622,8	797,4	412,8	377,6	360,4	613,1	460,8	436,8	446,2	662,9	554,0	604,0
34	246,6	414,5	371,7	435,6	549,7	345,5	328,0	547,8	545,3	361,0	396,5	424,7	652,7	534,8	1 004,0
35	405,5	544,3	558,1	580,6	946,2	302,0	325,9	518,4	584,0	674,8	435,0	412,1	511,8	608,3	807,6
36	266,5	329,5	415,3	373,6	445,5	298,0	305,3	356,0	343,1	478,1	441,2	372,5	396,4	599,5	642,9
37	417,4	565,1	873,1	886,0	1095	401,8	614,9	521,3	574,9	801,2	524,3	547,7	571,1	534,3	801,5
38	271,5	405,0	402,0	492,6	383,5	344,8	454,1	450,8	556,6	610,9	454,7	562,6	422,1	624,4	721,8
39	398,5	466,1	665,2	634,3	758,9	377,2	505,9	436,1	635,6	622,0	487,9	514,8	549,3	698,9	515,2
40	1168	1145	1362	1211	1285	404,0	575,6	791,9	801,5	761,6	469,8	636,4	794,5	698,8	823,7
41	476,8	517,9	1178	671,3	691,8	559,5	352,2	875,0	986,8	1097	724,2	760,0	1041	710,7	887,3
42	323,3	361,8	527,3	370,3	535,3	379,6	432,1	647,3	452,4	740,6	418,1	478,7	598,4	787,3	693,6
43	464,3	830,4	686,1	858,2	855,6	462,8	523,7	669,1	539,6	675,2	527,3	623,6	763,5	802,5	732,7
44	285,6	372,5	469,0	419,7	474,2	460,2	444,9	498,0	477,2	424,2	460,2	462,6	445,7	705,0	586,7
45	445,6	762,5	724,6	767,2	808,6	352,7	496,2	547,2	428,8	700,5	400,8	442,8	659,1	705,8	667,2
46	231,3	275,3	310,6	396,9	349,3	333,3	425,6	546,7	454,7	771,7	552,2	476,9	565,5	635,9	670,2
47	186,5	476,9	851,5	626,3	653,2	305,8	392,2	625,4	613,5	846,7	492,6	602,7	737,5	943,0	772,2
48	192,7	374,8	349,7	451,3	406,5	263,0	315,0	395,3	457,7	469,7	337,4	359,3	512,6	630,9	697,0
Mean	379,8	528,8	642,3	612,4	689,7	375,2	429,3	549,2	566,6	656,0	472,4	507,7	617,8	673,4	726,7
4. DRI (Open road)															
49	443,2	264,4	397,0	473,5	377,9	807,4	770,8	760,4	646,0	611,8	551,3	515,3	655,2	591,9	817,6
50	294,4	590,1	524,3	597,5	547,9	427,8	437,2	622,8	673,0	631,4	638,6	661,1	652,0	925,3	767,8
51	257,1	282,3	466,1	481,8	420,7	361,5	330,1	463,7	727,2	617,0	313,2	334,7	414,5	580,7	609,8
52	248,7	440,9	590,9	637,3	605,5	471,9	570,3	612,0	672,9	708,6	455,2	476,7	609,4	728,2	826,3
53	311,8	369,3	472,3	563,2	513,3	506,5	580,9	647,8	686,4	575,0	645,9	595,4	772,8	823,1	958,0
54	295,8	387,9	473,4	697,2	616,8	486,5	572,3	738,5	789,6	622,3	375,1	782,9	701,9	782,1	903,3
55	294,8	376,8	602,9	638,8	579,6	385,3	517,8	517,4	725,2	733,8	365,2	389,7	512,9	689,1	536,7
56	350,7	753,0	1273	1089	1078	660,5	532,8	798,9	819,8	910,6	648,2	596,3	694,1	901,0	659,8
57	278,1	339,0	413,2	556,2	633,2	359,0	377,3	448,0	641,8	795,4	322,2	374,7	385,9	656,7	648,1
58	564,6	814,6	975,7	1062,1	1299,2	490,4	579,0	751,1	818,9	829,3	511,6	525,5	715,4	737,5	625,6
59	246,3	309,8	358,5	516,9	432,9	285,5	311,6	429,3	525,2	455,3	292,6	300,0	371,7	456,3	527,2
60	418,8	663,7	890,9	1044	1055	363,5	607,3	928,1	733,7	870,4	471,7	645,7	730,9	794,1	1 280,0
61	249,9	310,2	386,5	518,6	647,5	428,2	514,9	544,0	716,1	737,8	377,0	380,1	537,4	587,6	775,1
62	226,4	297,6	341,3	508,8	341,6	334,9	405,0	493,4	575,2	614,1	335,9	424,3	427,9	696,6	529,8
63	282,0	369,2	428,0	571,2	399,5	366,1	457,9	511,1	610,6	621,3	483,7	390,6	497,6	584,5	570,2
Mean	317,5	437,9	572,9	663,7	636,6	449,0	504,3	617,8	690,8	688,9	452,5	492,9	578,7	702,3	735,7

Table E.8 — Mean RT (ms) and standard error (ms) across participants, by site, DRT and task condition for the four additional sites

No.	Site	Setup	n		TDRT					HDRT					RDRT				
					B	N0	N1	SE	SH	B	N0	N1	SE	SH	B	N0	N1	SE	SH
5.1	JCI	Simulator	20	ave						453			712	755					
				se						25,2			27,7	32,8					
5.2	JCI	Not drive	20	ave						309			598	721	544			789	
				se						14,6			19,7	40,6	31,7			42,6	
6.1	MIROS	Road	16	ave	245	364	410												
				se	7,0	25,5	28,0												
6.2	MIROS	Simulator	30	ave	355	504	638	657	732	421	527	630	679	764					
				se	13,7	24,7	37,8	32,4	51,2	16,6	22,5	27,7	28,2	37,9					
7.1	TUM	Simulator	18	ave	407	541	678[a]	732	699	381	455	654[a]	681	712	479	539	641[a]	794	780
				se	30,2	37,5	56,2	43,2	50,4	12,8	18,0	43,7	33,2	24,0	22,1	25,4	35,7	39,5	30,7
7.2	TUM	Not drive	18	ave	373	472	585[a]	590	634	345	403	515[a]	557	609	422	473	542[a]	661	710
				se	15,1	34,1	39,1	38,2	48,1	11,1	15,5	29,8	23,1	21,3	20,2	21,9	28,2	33,0	31,2
8.1	Volvo	Simulator	16	ave	290	431	582	656	598										
				se	13,1	27,8	60,0	39,5	35,7										
8.2	Volvo	Not drive	16	ave	209	343	419	533	465										
				se	5,6	34,1	45,8	27,9	37,3										

[a] N_2 not N1 for site 7 (TUM).

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