BS ISO 17488:2016

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

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National foreword

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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).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

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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*.

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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

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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.

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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.

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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.

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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.

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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*.

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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.

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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

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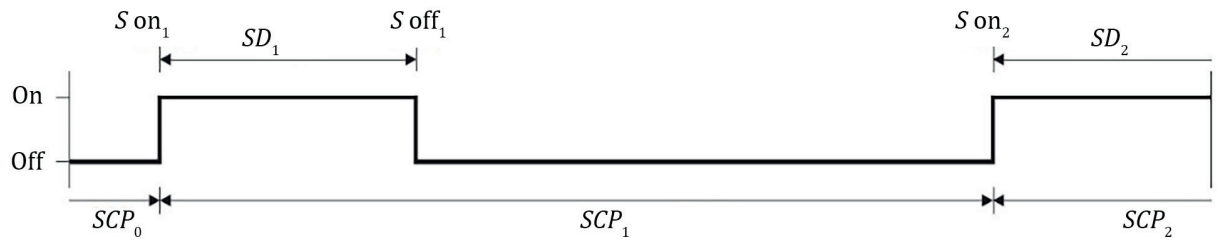
in the forward view of the participant. Finally, in the tactile DRT (TDRT), a tactile vibrator is placed on the participant's body. These stimulus presentation methods are described in further detail below. Guidelines for the selection of stimulus presentation mode depend on the purpose of the experiment 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)

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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).

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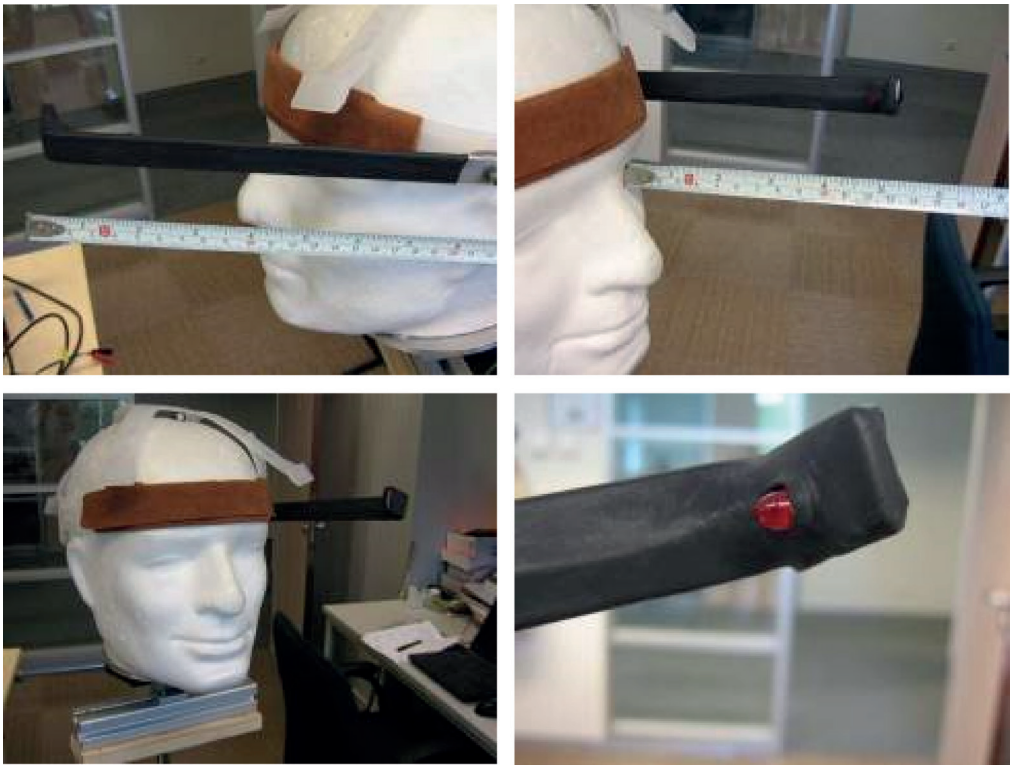

Figure 3 — Illustration of the setup for the head-mounted DRT

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

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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

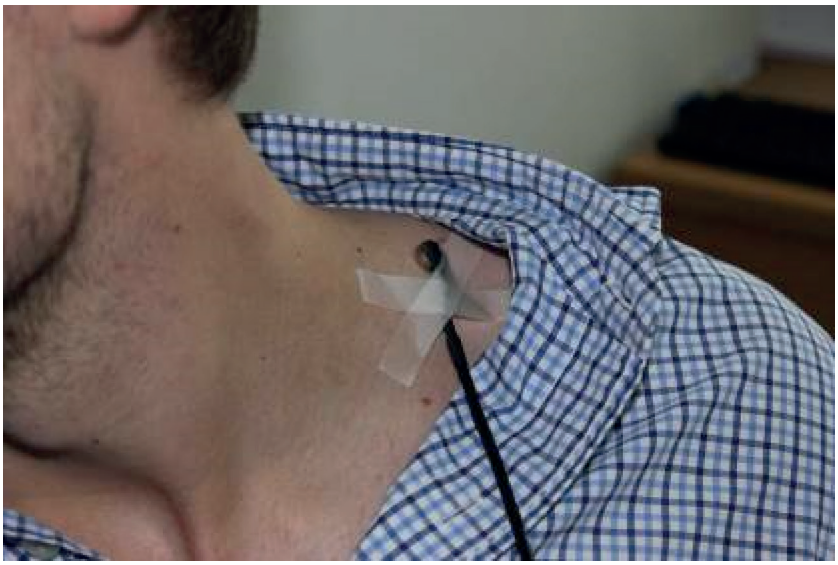

Figure 4 — Placement and attachment of the tactor

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

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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.

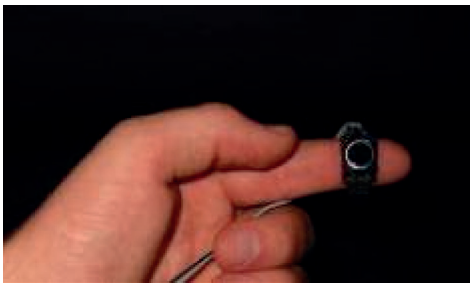

Figure 5 — Illustration of the setup for the response micro-switch

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;

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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

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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.

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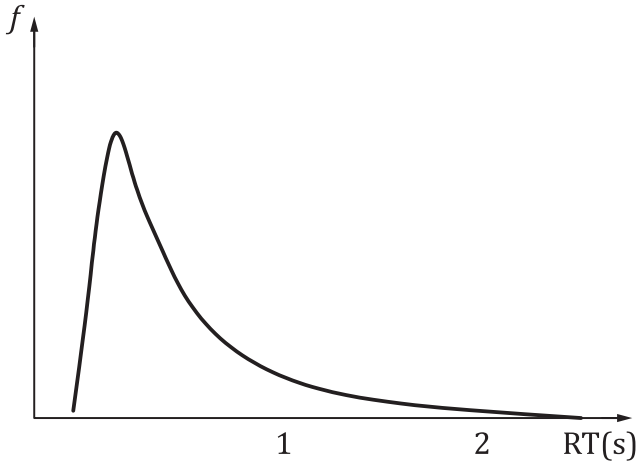

Figure 6 — Reference RT distribution for checking DRT data quality

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.

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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.

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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.

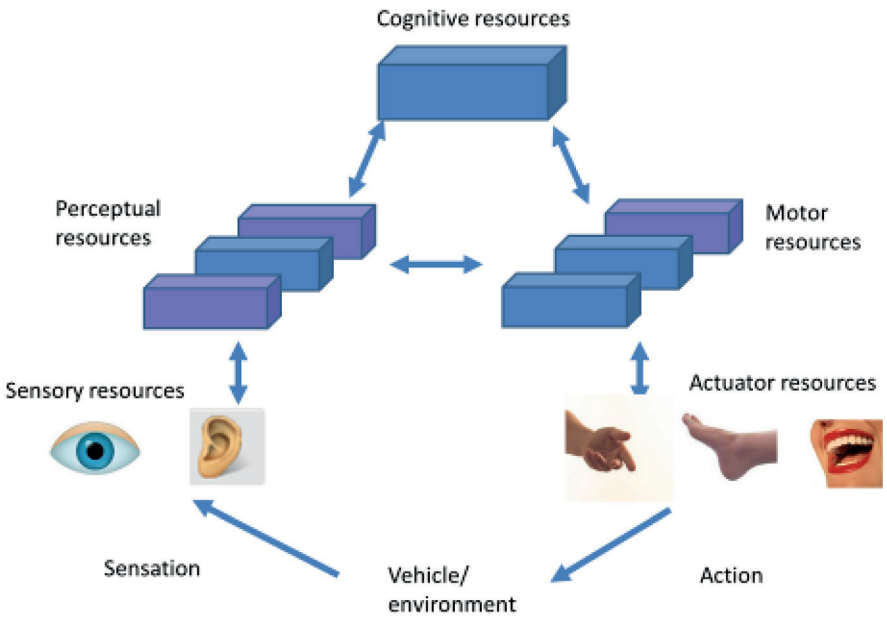

Figure A.1 — Illustration of the three-level resource model outlined in the text

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.

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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.

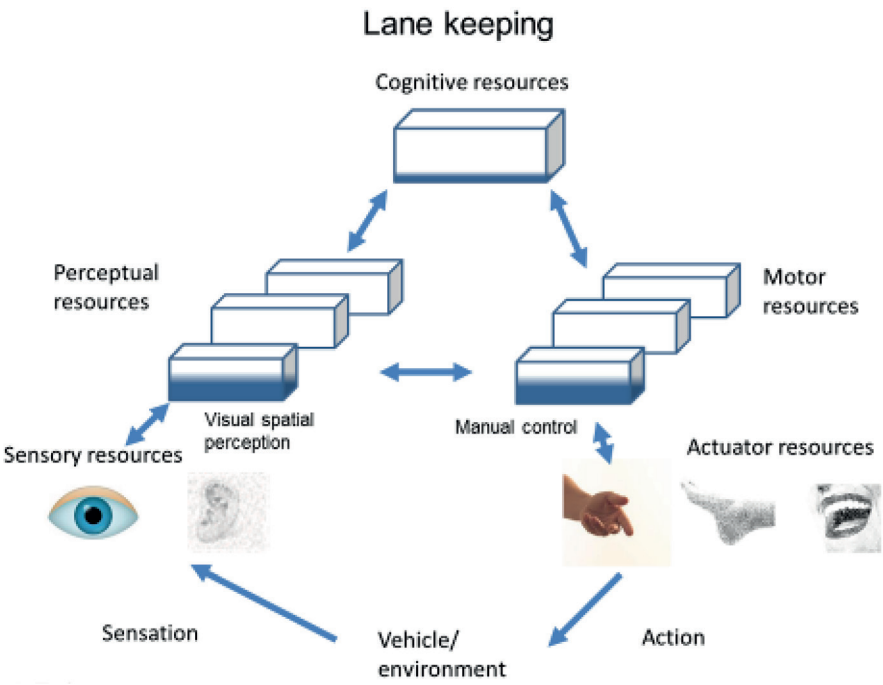

Figure A.2 — Hypothetical resource allocation for lane keeping in normal (non-demanding) driving conditions

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).

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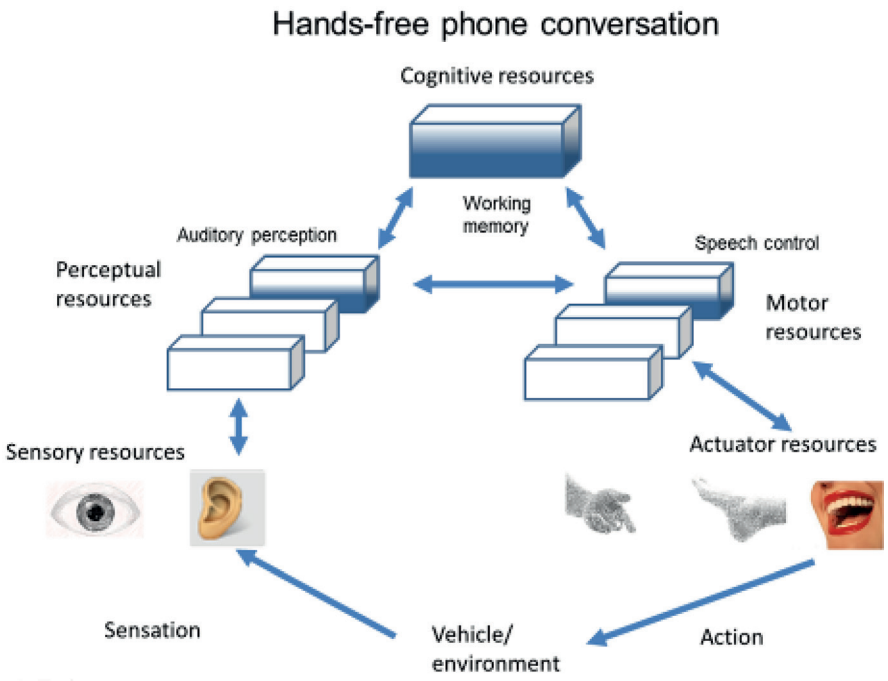

Figure A.3 — Hypothetical resource allocation for hands-free phone conversation

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.

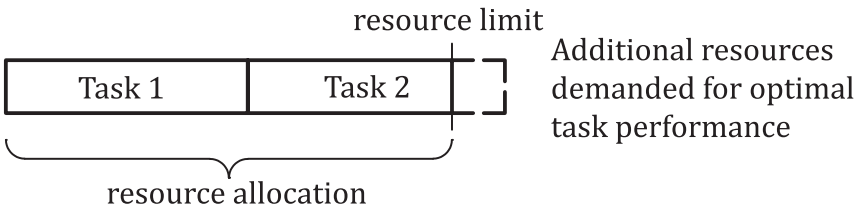

Figure A.4 — Illustration of total resource demands needed for satisfactory performance on two tasks exceed the available resource

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

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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.

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