Submitted by the expert of Japan

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Results of the Study on ACSF Transition Time

National Traffic Safety and Environment Laboratory, Japan

4th Meeting of ACSF Informal Group, 25-27 Nov. 2015

N T S E L

Objectives of the Study

1. To study transition from ACSF to the driver using a driving simulator when the driver needs manual operation while using the ACSF on a highway.

   (1) Time required for the driver to become aware of the situation and begin manual operation in a safe manner

   - **Response time up to holding the steering wheel**
   - **Behavior of the vehicle after switching to manual operation**

   (2) Necessity of warning when an another vehicle approaches, or against a stationary obstacle

2. To conduct experiments with the following scenarios in order to study what is described above:

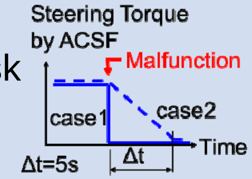
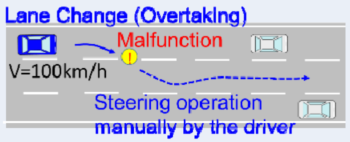
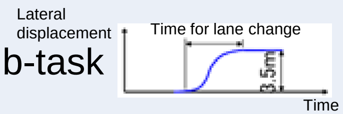
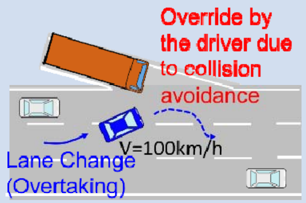
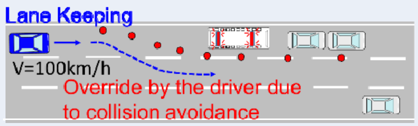
   (1) Malfunction occurs when running a curve (2) Malfunction occurs when changing lanes

   (3) A merging vehicle approaches (4) The number of lanes decreases

3. To study differences in transition time between when there is or is not a sub-task that distracts the driver’s forward attention.
4. To conduct experiments involving 16 subjects in their 30’s to early 70’s.
5. To propose a transition time required for ACSF based on the results of the experiments mentioned above.

Scenarios for Experiments

4 scenarios were created where the driver's manual operation is required.

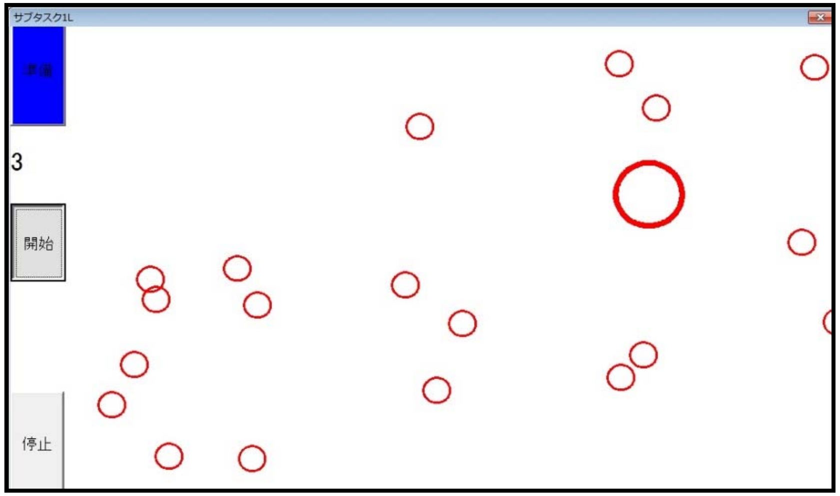
Scenario	Description	Variables
(1) Malfunction occurs when running a curve	 ● ACSF malfunctions when running a left highway curve. ● Upon receiving malfunction warning, the driver begins manual operation.	● Time from malfunction warning to system stop (4s, 2s, 0s) ● How to stop ACSF (cases 1 and 2) ● With/without sub-task 
(2) Malfunction occurs when changing lanes	 ● ACSF malfunctions when automatically changing lanes on a straight highway. ● Upon receiving malfunction warning, the driver begins manual operation.	● Time from malfunction warning to system stop (4s, 2s, 0s) ● Duration of lane change (3s, 6s, 10s) ● With/without sub-task 
(3) A merging vehicle approaches (necessity of warning)	 ● A merging vehicle approaches when automatically changing lanes on a straight highway. ● The driver overrides ACSF to avoid collision.	● With/without warning of merging vehicle approach (No warning, warning at TTC=4s before) ● With/without sub-task
(4) The number of lanes decreases (necessity of warning)	 ● The car approaches a point where the lanes decrease on a straight highway. ● The driver overrides ACSF to avoid collision.	● With/without warning of lane decrease (No warning, warning at TTC=4s before) ● With/without sub-task

Experiment on Transition Time Differences due to Sub-task

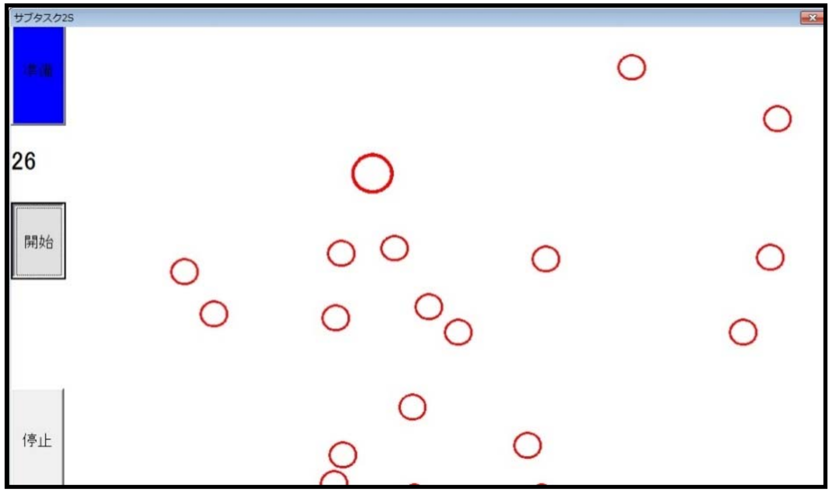
- Sub-task was set to scenarios (1) to (4) to conduct experiments with/without sub-task.
- Many circles with one larger circle are shown on a touch panel display for sub-task and the driver was asked to touch the large one with the finger. The arrangement of circles on the screen is random and changed at a predetermined interval.
- Sub-task has two levels based on the size of the large circle and display change interval. Senior persons took the lower-level (sub-task 1 as shown below) sub-task only.
- Subjects were told to do sub-task continuously during experiment except when they think manual steering wheel operation is necessary.

<Screen display samples>

Sub-task 1 (changes every 3s.)(Easy)

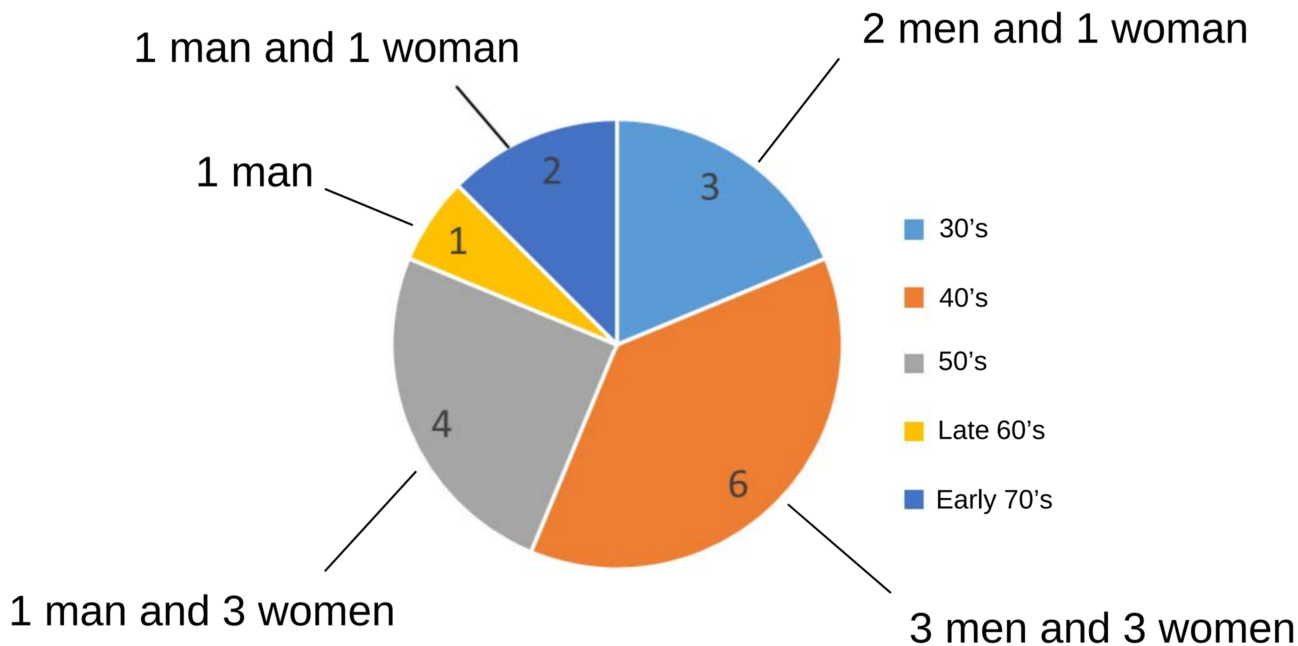


Sub-task 2 (changes every 2s.) (Difficult)



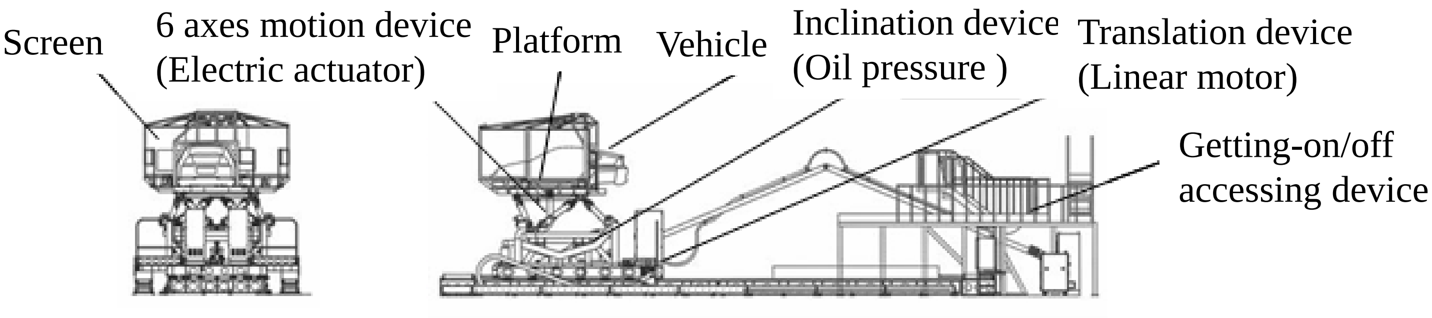
Subjects of the Experiments

- A total of 16 general drivers participated in the experiments (breakdown is shown below).
- Before the start of the experiment, the subjects fully learned how to drive when ACSF and ACC work normally and how to drive manually with ACSF and ACC off.



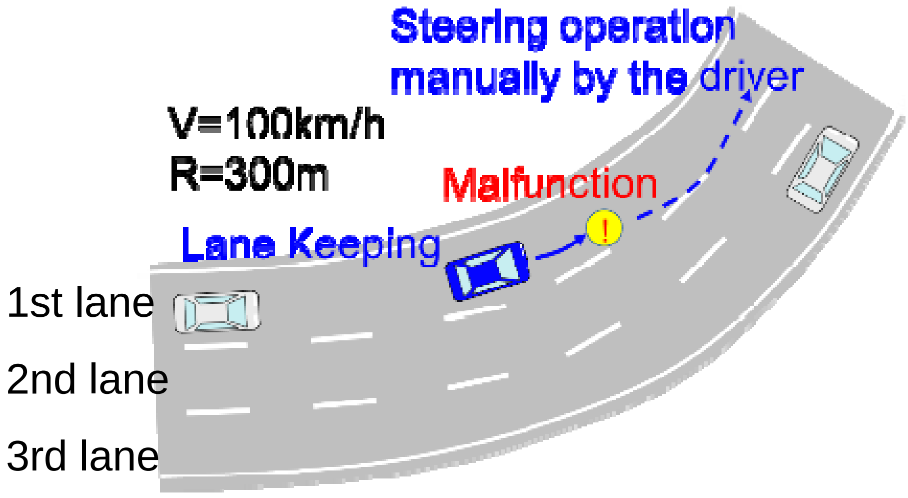
Breakdown of subjects

Driving Simulator Used in the Experiments

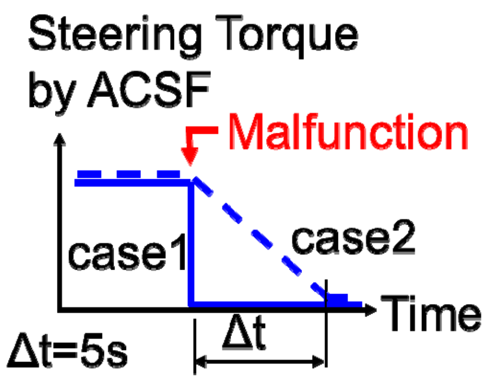


- A driver can use ACSF category E (lane keeping and lane change) on the highway, and also he/she can use ACC on the highway.
- To suppress the tolerance of vehicle speed by each driver, ACC was used during the experiment.
- Both ACSF and ACC can be overridden individually by the driver at any time.

Experiment Overview – (1) Malfunction when Running a Curve－



- ACSF malfunctions when running a left curve on a highway.
- Upon receiving malfunction warning, the driver begins manual operation.



Variables

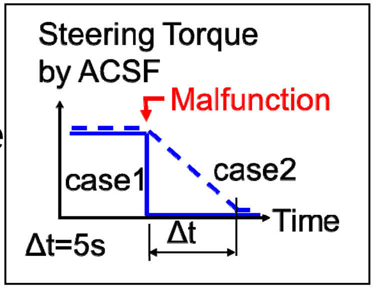
- Time from malfunction warning to system stop (4s, 2s, 0s)
- How to stop ACSF (case 1, case 2)
  - In case 1, ACSF is stopped suddenly.
  - In case 2, ACSF is stopped gradually.
- With/without sub-task

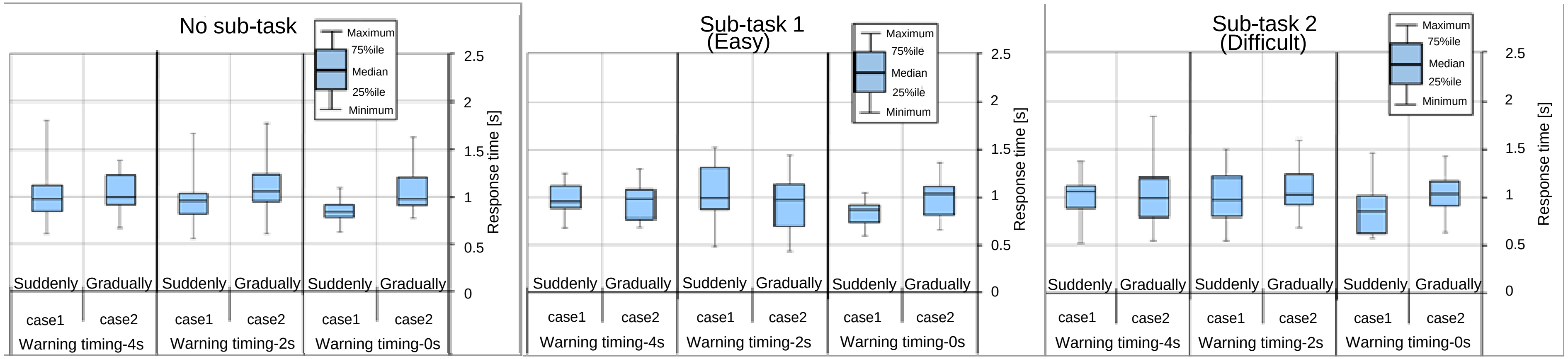
Results – (1) Malfunction when Running a Curve -

Malfunction warning timing and response time*

- Regardless of with/without sub-task, or sub-task level, the response time was about **1.8s at maximum**, which is relatively quick, and no significant difference was observed.
- In the combination of warning timing of 0s and case 1, where the driver had minimum time allowance, the response time was about 0.2s shorter that the other cases.

*Definition of response time
Time spent from when malfunction warning is given (0s) to when the driver holds the steering wheel.

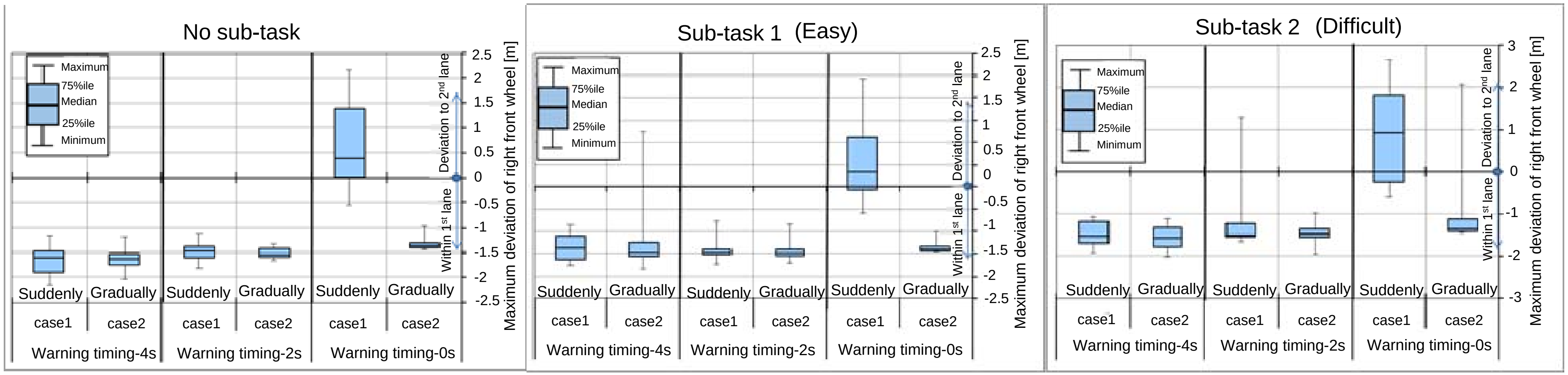


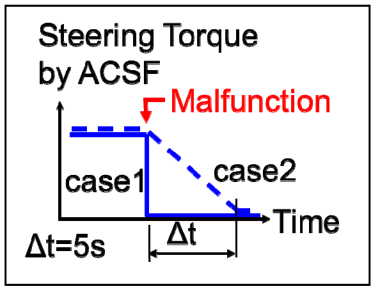


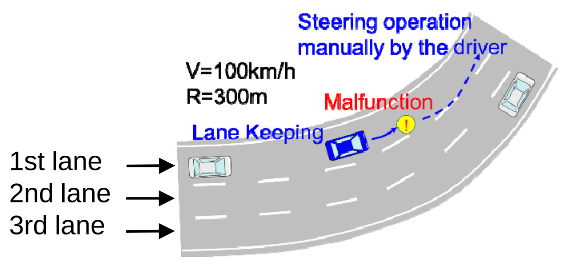
Results – (1) Malfunction when Running a Curve -

Malfunction warning timing and maximum deviation of the right front wheel*

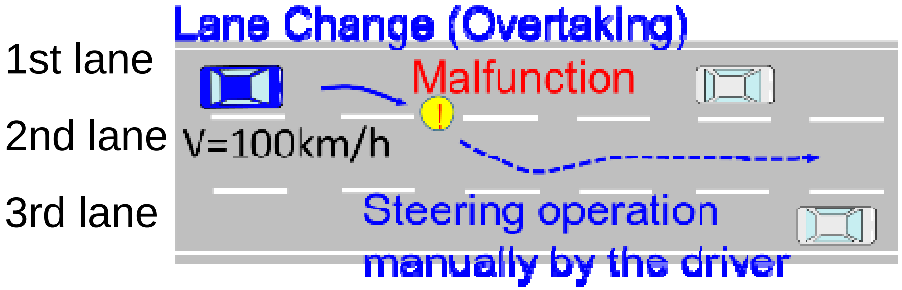
- Regardless of with/without sub-task, or sub-task level, **<u>many subjects deviated the right front wheel to the 2nd lane side in combination of 0s warning timing and case 1</u>**.
- Since in other combinations, the wheel remained in the 1st lane, **<u>if warning is given at least 2s before, deviation from the lane can be prevented.</u>**
- When ACSF was stopped gradually (case 2), 0s warning timing was particularly effective in preventing lane deviation.



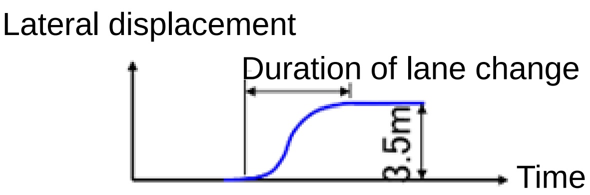




Experiment Overview - (2) Malfunction when Changing Lanes-



- ACSF malfunctions when automatically changing lanes on a straight highway.
- Upon receiving malfunction warning, the driver begins manual operation.



Variables

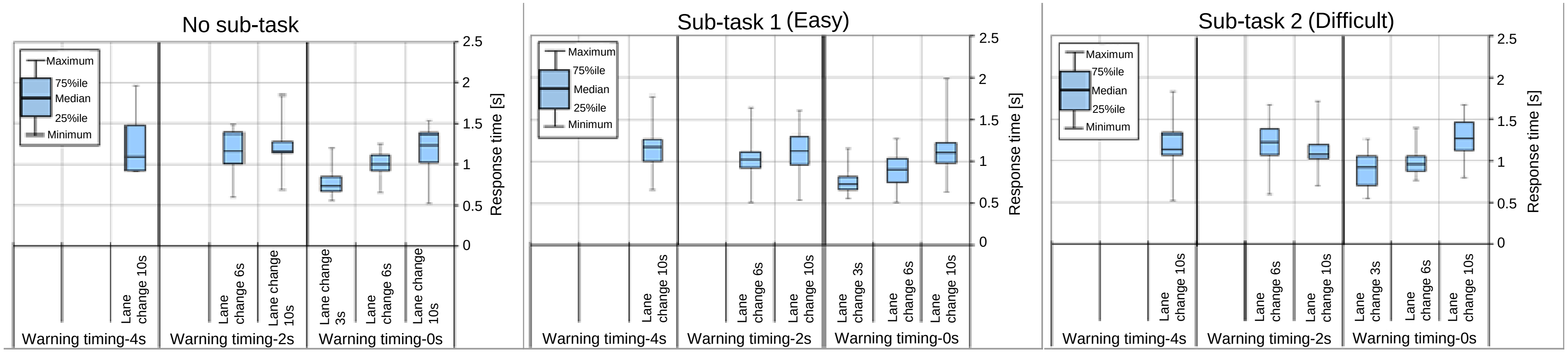
- Time from malfunction warning to system stop (4s, 2s, 0s)
- Duration of lane change (3s, 6s, 10s)
- With/without sub-task

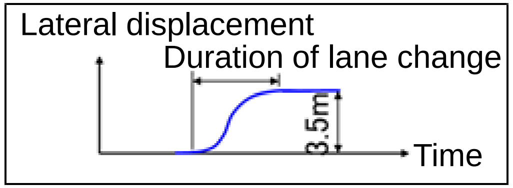
- Regardless of differences in variables mentioned above, malfunction was supposed to occur around the middle (steering angle≒0 deg) when moving from the 1st to 2nd lane laterally.
- ACSF was stopped suddenly.
- Since it was not realistic for ACSF to begin lane change after malfunction was detected, the case when warning timing was before the start of lane change was excluded from consideration. (e.g. warning timing of 4s and lane change duration of 3s)

Results - (2) Malfunction when Changing Lanes -

Malfunction warning timing and response time

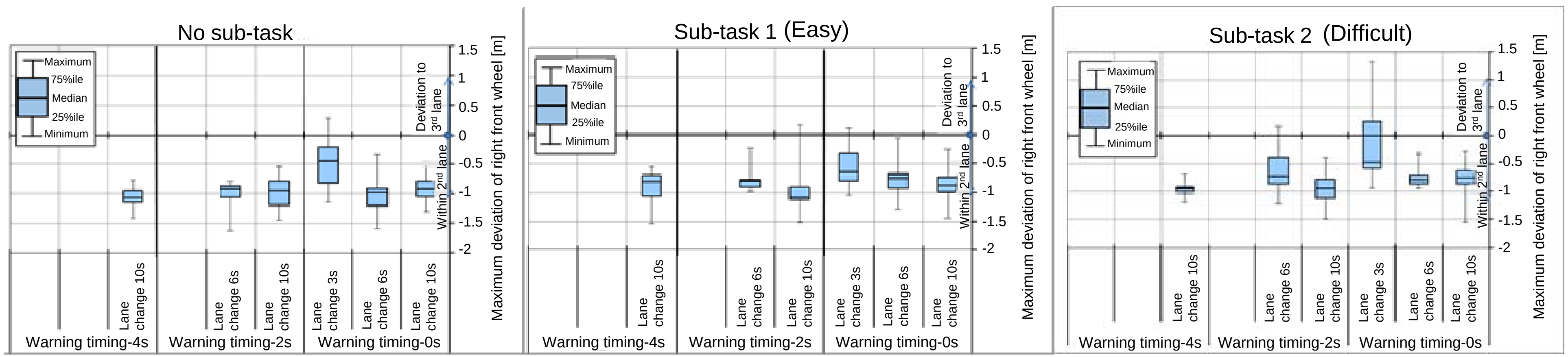
- Regardless of with/without sub-task, or sub-task level, the response time was about **<u>2s at maximum</u>**, which is relatively quick.
- In the combination of “0s warning timing” and lane change duration of 3s, where the driver had minimum time allowance, the response time was about 0.3 to 0.4s shorter that the other cases.



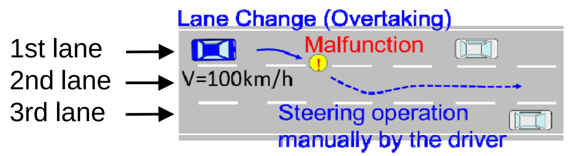


Malfunction warning timing and maximum deviation of the right front wheel

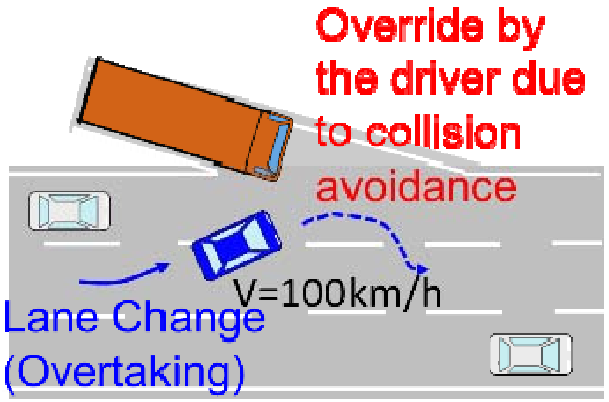
- **<u>In combination of lane change duration of 3s and warning timing of 0s with sub-task 2, more than one subject deviated the right front wheel to the 3^{rd} lane.</u>**
- Since in other combinations, the wheel remained in the 2^{nd} lane, **<u>if warning is given at least 2s before, deviation from the lane can be prevented.</u>**
- Lane change duration of 6s or longer was particularly effective in preventing lane deviation at the time of malfunction.



- In some cases, after malfunction warning was given, the driver manually stopped lane change and remained on the 1^{st} lane. But since in these cases, there was no possibility of deviation to the 3^{rd} lane, they were excluded from the determination of the maximum deviation.



Experiment Overview – (3) Merging Car Approaching -



- A merging vehicle approaches when automatically changing lanes on a straight highway.
- The driver overrides ACSF to avoid collision.

Variables

- With/without warning of an approaching vehicle
  (No warning, warning at TTC=4s before)
- With/without sub-task

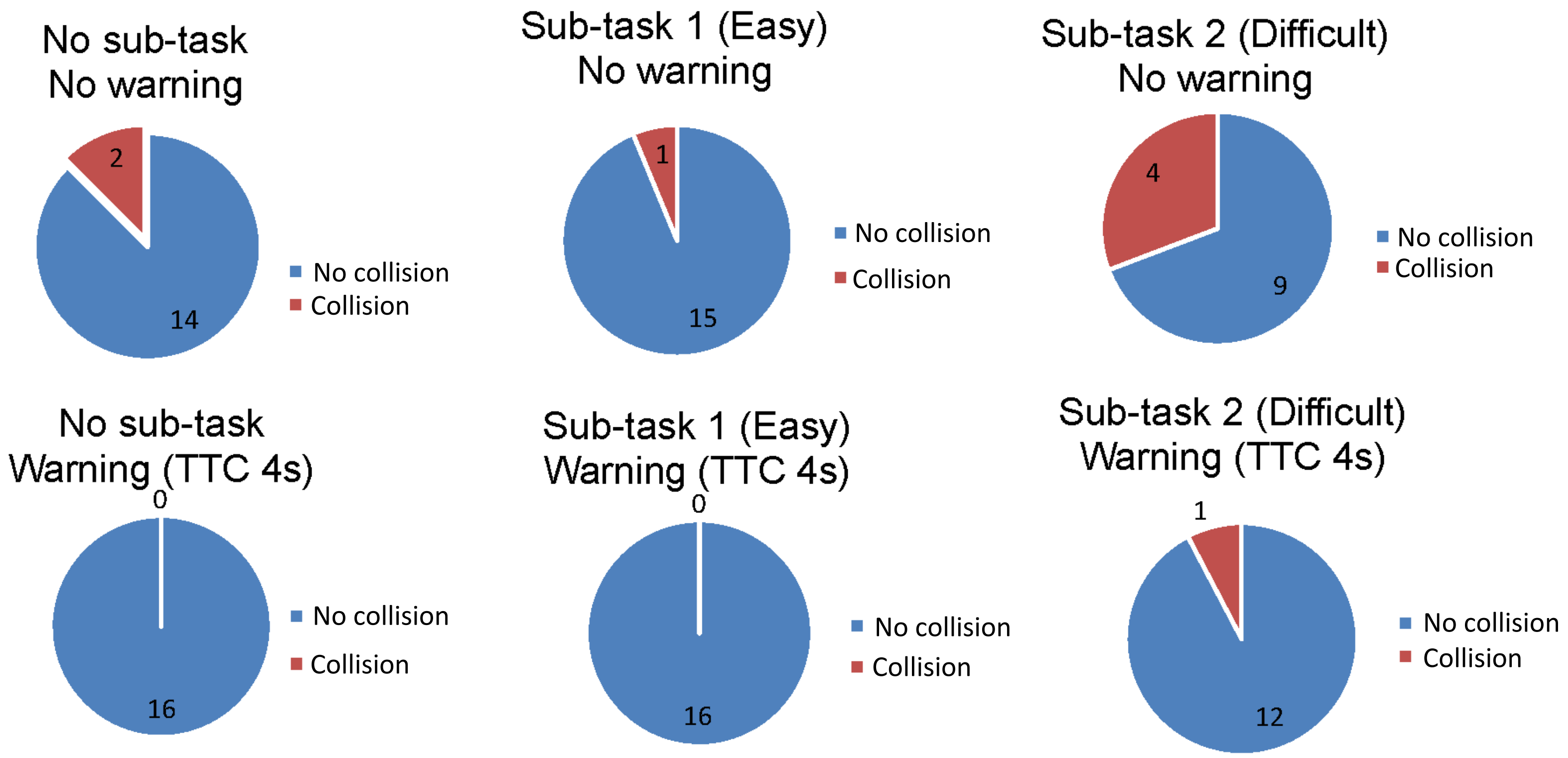
- TTC 4s means 4 seconds before a possible collision with the merging vehicle (TTC 0s) which would occur if the driver does not manually avoid collision.

Results – (3) Merging Car Approaching -

The rate of collision with the merging vehicle

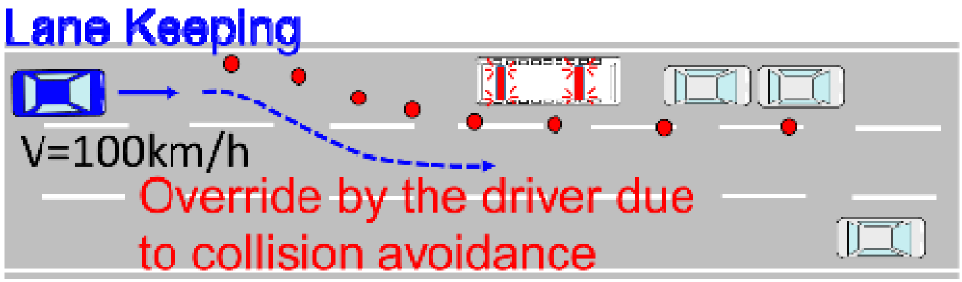
- In all sub-task cases (no sub-task, sub-tasks 1and 2), **when no warning was given, some subjects collided with the merging vehicle.** The **collision rate was higher in the case of sub-task 2**, where the driver's forward attention was more greatly distracted.

- **When warning was given, collision was avoided in almost all the cases.**



Experiment Overview – (4) Lane Decrease -

- The car comes to a point where the number of lanes decreases on a straight highway.
- The driver overrides ACSF to avoid collision



Variables

- With/without warning of lane decrease
  (No warning, warning at TTC=4s before)
- With/without sub-task

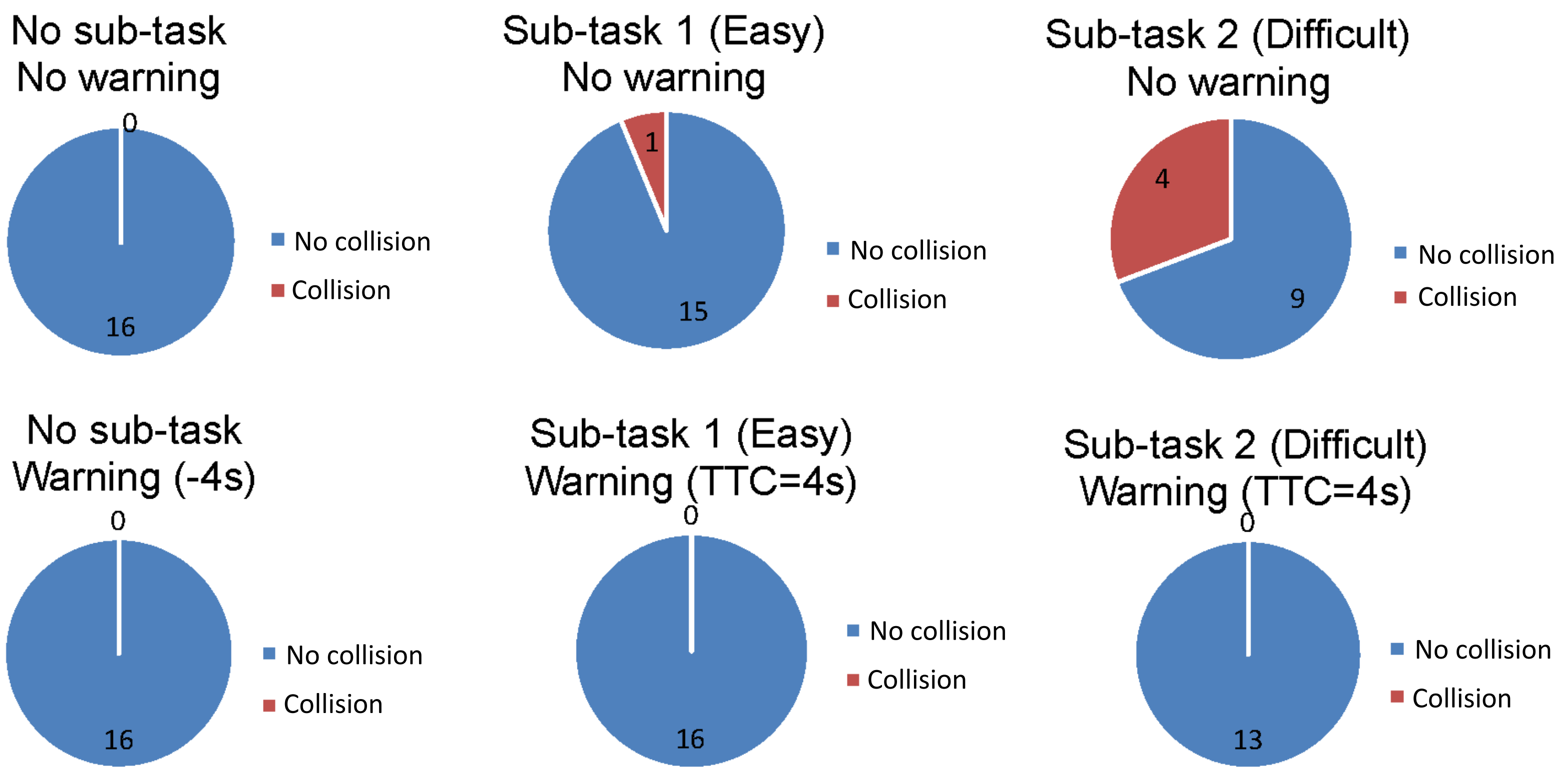
- TTC 4s means 4 seconds before a possible collision with the nearest stationary obstacle (TTC 0s) which would occur if the driver does not manually avoid collision.

Results – (4) Lane Decrease -

The rate of collision with a stationary obstacle

- In cases of sub-tasks 1 and 2, **<u>when no warning was given, some subjects collided with a pylon or stationary vehicle.</u>** The **<u>collision rate was higher in the case of sub-task 2</u>**, where the driver's forward attention was more greatly distracted.

- **<u>When warning was given, collision was avoided in all the cases.</u>**



Summary of the Experiment Results

The results under all the sub-task conditions are summarized below as the results on the safest side. (Max. response time, max. lane deviation rate, and collision rate)

		Warning of 0s		Warning of 2s before		Warning of 4s before	
		Response time (max)[s]	Rate of deviation [%]	Response time (max)[s]	Rate of deviation [%]	Response time (max)[s]	Rate of deviation [%]
(1) Malfunction when running a curve	Case 1 (Suddenly)	1.5	75	1.7	7.7	1.8	0
	Case 2 (Gradually)	1.6	7.7	1.8	0	1.8	7.7
(2) Malfunction when changing lanes	Lane change duration 3s	1.3	30.8	-	-		-
	Lane change duration 6s	1.4	0	1.7	7.7	-	-
	Lane change duration 10s	2.0	0	1.9	7.7	2.0	0

Lane deviation rate is high.

Lane deviation rate is 0 or extremely low.

	Rate of collision [%]	
	Warning（TTC=4s）	No warning
(3) Merging vehicle approach	7.7	30.8
(4) Lane decrease	0	30.8

Collision rate is high.

Summary

- No clear difference was observed in the response of the driver when manual operation was required between with and without sub-task.

- The results of the experiments show that at least 2 seconds are needed as the transition time regardless of with/without sub-task.

- This is because the maximum response time for the driver to hold the steering wheel for manual operation after malfunction warning was given was 2 seconds, and because virtually no lane deviation occurred when warning was given 2 seconds before the stop of the system.

- When ACSF malfunctions, a gradual decrease in steering torque was effective in preventing lane deviation during transition to manual operation when running a curve.

- Lateral movement of 6s or more during automatic lane change was effective in preventing lane deviation during transition to manual operation when malfunction occurs during lane change.

- Warning to the driver is necessary when a merging vehicle approaches or the number of lanes decreases and the control of ACSF cannot deal with the situation. If warning is given at TTC=4s before, with allowance, most drivers are able to switch to manual operation without collision.