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1 **Impact of the driver's visual engagement on situation awareness and**
2 **takeover quality**

3
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27 **ABSTRACT**

28 *During automated driving (SAE Level 3), drivers can delegate control of the vehicle and*
29 *monitoring of the road to an automated system. They may then devote themselves to tasks*
30 *other than driving and gradually lose situational awareness (SA). This could result in*
31 *difficulty in regaining control of the vehicle when the automated system requires it. In this*
32 *simulator study, the level of SA was manipulated through the time spent performing a non-*
33 *driving task (NDRT), which alternated with phases where the driver could monitor the*
34 *driving scene, prior to a critical takeover request (TOR). The SA at the time of TOR, the*
35 *visual behaviour after TOR, and the takeover quality were analysed. The results showed*
36 *that monitoring the road just before the TOR allowed the development of limited*
37 *perception of the driving situation, which only partially compensated for the lack of a*
38 *consolidated mental model of the situation. The quality of the recovery, assessed through*
39 *the number of collisions, was consistent with the level of development of SA. The analysis*
40 *of visual behaviour showed that engagement in the non-driving task at the time of TOR*
41 *induced a form of perseverance in consulting the interface where the task was displayed,*
42 *to the detriment of checking the mirrors. These results underline the importance of*
43 *helping the driver to restore good SA well in advance of a TOR.*

44
45 **Keywords:** Automated driving; Taker-over request; Human factors; Non-driving task;
46 Situation awareness.

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48

49 1. Introduction

50

51 Developments in the automotive industry have contributed to the creation of vehicles in
52 which increasing numbers of functions are delegated to an automated system. The Society
53 of Automotive Engineers International (SAE) has defined six levels of automation, from
54 the lowest level (Level 0) to the highest level of automation (Level 5; SAE International,
55 2016). At Level 3, the driver can delegate vehicle control and road monitoring to the
56 automated system on roads that meet certain conditions. This delegation allows drivers to
57 engage in non-driving tasks while the driving is automated. However, the driver must be
58 receptive at all times to a request to intervene from the automation and ready to serve as a
59 "fallback ready user". The driver must take over manual control of driving or, if that is not
60 possible, must achieve a minimal risk condition. The takeover request (TOR) can occur for
61 two reasons: first, the system may anticipate that the vehicle is approaching the end of its
62 operational domain, in which case it will be a planned and non-critical takeover. The
63 second reason is that the system may be not able to handle a situation, or a problem may
64 occur that prevents the system from operating properly.

65

66 Unplanned critical takeovers are sometimes characterised by a high level of hazard with a
67 short time to regain control of the vehicle. Numerous scientific works have studied the
68 risk factors during the takeover. Zhang et al. (2019) synthesised the results of 129 studies
69 analysing the takeover time according to various criteria, such as time budget (from 2 s to
70 15 s), traffic complexity, and driver age. They concluded that performing a non-driving
71 task, even without a handheld device, increased the takeover time compared to not
72 performing such a task. Task modality, classified as either auditory or cognitive, did not
73 influence the takeover time. Other studies have focused on situational awareness (SA) and
74 takeover (e.g. Endsley, 2018; Ma & Kaber, 2005; White et al., 2019; Winter et al., 2014).
75 The present study contributes to these efforts by studying how a non-driving related task
76 (NDRT) can affect the driver's SA and the takeover quality in a critical situation.

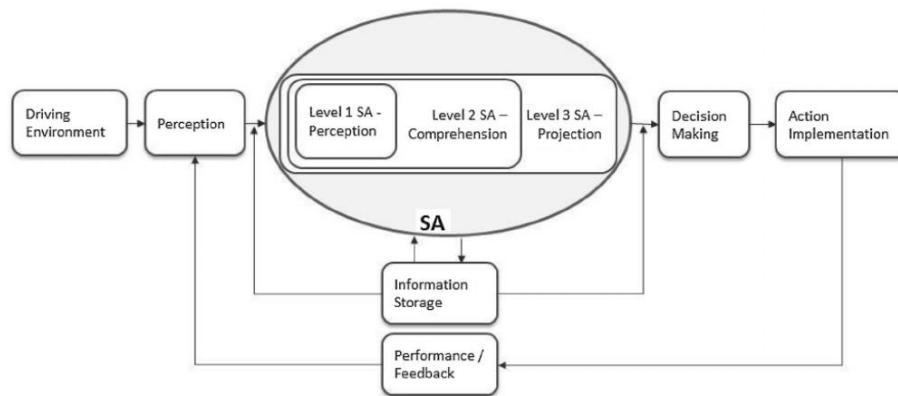
77

78 A major concern in the delegation of vehicle control and road supervision is that
79 automated systems can cause the driver to be "out-of-the-loop". To formalise this
80 problem, Merat et al. (2019) distinguished three states. When the driver acts on the
81 vehicle's controls and supervises the road, they are "in-the-loop". If they delegate the
82 operational control of the vehicle to the automated system but continue to monitor the
83 road scene, they are "on-the-loop". When the driver no longer monitors the situation, they
84 are considered to be "out-of-the-loop". In Level 3 automation, drivers may be on-the-loop
85 if they supervise the road or out-the-loop if they are engaged in non-driving activities.
86 Potential drivers of autonomous vehicles have been shown to want to perform new
87 activities that require attentional resources such as reading, writing messages, eating,
88 drinking, browsing the internet, or making phone calls (Pfleger et al. 2016; Shi & Frey,
89 2021). Drivers can thus be expected to engage in non-driving activities that may divert
90 their attention from the road (Naujoks et al., 2016). In turn, that engagement can lead to
91 impaired SA.

92

93 Situational awareness is a dynamic process that can be defined as the perception and
94 understanding of a context, which enables the individual to anticipate an impending
95 scenario. Endsley & Kiris (1995) proposed a three-level model. The first level of SA is the
96 perception of elements relevant to the task in the current situation. At the second level, the
97 operator integrates the perceived elements to understand their impact on the current
98 objectives. At the last level, the operator anticipates the dynamics of the elements to

99 predict how they will affect the environment and the operator's goals. In other words, SA
 100 displays different levels of information elaboration. The perception of the context (Level
 101 1) is based on immediate information, which is processed to give meaning to the current
 102 situation (Level 2). Because the construction of a mental model allowing projection into
 103 the future (Level 3) requires the integration of information over a longer period,
 104 monitoring of the road scene determines the quality of SA. Merat et al. (2019) illustrated
 105 how SA fits into the driving activity (see Figure 1).
 106
 107



108
 109 *Figure 1. SA in driving information processing; reproduced from Merat et al (2019)*
 110

111 During manual driving, performing a secondary task or talking with another person can
 112 impair SA (Gugerty et al., 2003; Heikoop et al., 2018; Ma & Kaber, 2005). For example,
 113 Green (1999) showed that self-paced glances at in-vehicle controls and displays typically
 114 did not exceed 1.2 s or 1.5 s. Rockwell (1988) also showed that drivers were loath to wait
 115 more than 2 s to obtain road information. This 2-s rule can be considered the critical value
 116 for distraction in cars. It appears to be the interval beyond which the absence of road
 117 scene monitoring critically impairs the perceptual determinants of SA.
 118

119 Because drivers are prone to be distracted and no longer control the vehicle, the 2-second rule
 120 ceases to be valid in highly automated vehicles. For example, Zeeb et al. (2015) performed a
 121 simulator study in which participants had to drive for 26 min in highly automated driving.
 122 They had to perform “Texting” and “Internet Search” on the multimedia system. By the end
 123 of the driving task, some drivers spent up to 55 s without looking at the road. Drivers who
 124 spent considerable time without looking at the road showed longer braking reaction times
 125 and higher collision rates than those who did not. Winter et al. (2014) also presented a
 126 meta-analysis of 32 studies about the impact of adaptive cruise control and highly automated
 127 driving on workload and SA. Highly automated driving impaired SA when the driver chose to
 128 perform an NDRT at the expense of monitoring the driving scene (Carsten et al., 2012; Merat
 129 et al., 2019). Marti et al. (2021) reported that the difficulty of a NDRT performed before a
 130 TOR did not influence the success of a critical takeover. However, looking at the task display
 131 at the time of TOR increased the risk of collision.
 132

133 Studies in various fields have investigated the relationship between situation awareness
 134 and visual strategies. In the air traffic control domain, Moore & Gugerty (2010) found that
 135 controllers' SA score depended on visual attention paid not only to the most important
 136 aircrafts, but also to surrounding aircrafts. Too much visual focus on important aircrafts
 137 can create attention tunnelling and degrade SA. Van de Merwe et al. (2012) studied the
 138 gaze behaviour of pilots when a malfunction occurred during a flight. Gaze entropy (visual

139 scanning activities around the cockpit) increased as SA decreased. Gartenberg et al. (2014)
140 tried to characterize SA recovery after a task interruption. Shorter fixation durations,
141 increased the number of objects scanned, longer resumption lags, and a greater likelihood
142 of refixating objects that were previously looked at were identified as indicators of SA
143 recovery. More closely related to the autonomous vehicle domain, Kunze et al. (2019)
144 showed that drivers who performed shorter fixations in a peripheral search task during the
145 40 seconds before a TOR exhibited higher SA scores. In another study, Liang et al. (2021)
146 found that greater gaze dispersion and more time looking at the road scene were positively
147 correlated with SA scores. They also showed that previous engagement in a NDRT impairs
148 SA after the TOR. Thus, SA depends on an appropriate distribution of visual attention.

149
150 It is therefore reasonable to assume that the quality of SA depends on the driver's visual
151 behaviour and determines the driver's ability to safely regain control of the vehicle. This is
152 especially true in complex situations, such as unexpected obstacle avoidance. A question
153 is how long it takes to reconstruct a sufficiently elaborated SA. It is hypothesised that if
154 the driver's perception of the immediate context is sufficient (Level 1 SA), looking at the
155 road 2 s before resuming vehicle control would be effective to obtain a good quality of
156 takeover. This outcome would be independent of the driver's visual behaviour during the
157 preceding automated driving phase. By contrast, if there is an advantage to having more
158 elaborate SA (i.e., an appropriate mental model of the situation built over time), takeover
159 quality should improve when the driver has not been distracted for long before resuming
160 control.

161
162 The present study examines the impact of visual distraction on the quality of vehicular
163 control. Two temporal windows of visual engagement in a NDRT preceding the TOR are
164 distinguished. This gives rise to four experimental conditions in which the gaze behaviour
165 and the quality of the takeover will be analysed.

166 - The first group of participants will not have a NDRT to perform. They will have every
167 opportunity to build a good Level 3 SA over the course of autonomous driving and they
168 will be attentive to the road scene when the TOR is delivered.

169 - The second group of participants will be placed in identical conditions to the previous
170 one, except that they will be distracted by the NDRT for the two seconds before the TOR.
171 This condition will therefore allow to evaluate the influence of impairing the immediate
172 perception of the road scene in drivers who have had time to build up a good SA
173 beforehand.

174 - The third group will have to perform the NDRT during an extended period of 5 minutes
175 but 2 seconds before the TOR. The NDRT interruption will allow the driver to reacquire a
176 vision of the immediate driving environment right before the TOR intervenes. These
177 participants will therefore not be able to build and update SA during the NDRT, but will
178 not be distracted from the road scene at the time of the TOR.

179 - The last group of participants will have to perform the NDRT until the TOR. SA will be
180 the most severely impacted and the TOR will intervene when the driver's gaze is not on
181 the road. The driver will only have the time between him and the obstacle to analyse the
182 situation and decide on the manoeuvres to be executed.

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186 **2. Materials and Methods**

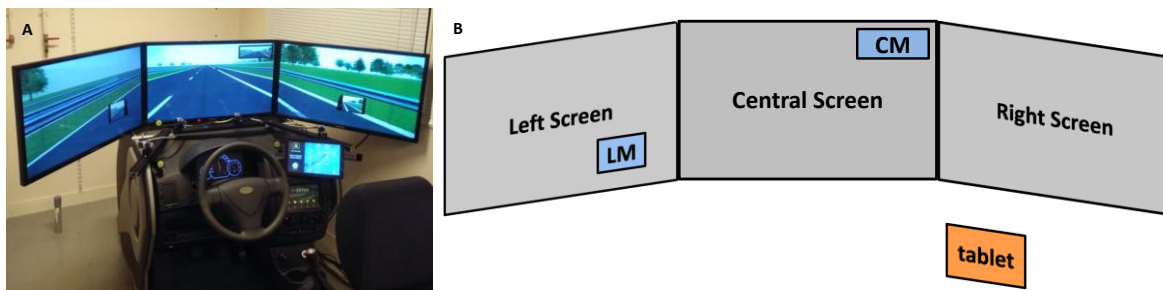
187 **2.1. Participants**

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189 There were 88 participants (33 women, 55 men) aged between 18 and 56 years ($M = 24.01$,
190 $SD = 7.67$) in the study. They all held a valid driving licence and had average driving
191 experience of 7,704 km/year ($SD = 8500$, $Min = 200$, $Max = 40000$). They had normal vision
192 or vision corrected with contact lenses. All participants gave written informed consent in
193 accordance with the Declaration of Helsinki. The experiment was approved by the non-
194 interventional research ethics committee of Nantes University (CERNI, IRB #IORG0011023;
195 approbation #08072021-3).

197 2.2. Experimental setup

198
199 Participants drove on a fixed-base simulator (see Figure 2) consisting of an adjustable seat, a
200 steering wheel with force feedback, a gear lever, clutch, accelerator and brake pedals. The
201 software SCANeR Studio (v1.8) displayed the driving scene on three screens at a field of
202 view of about 120° . An 11" tablet, positioned about 35° to the right and 15° below the
203 direction straight ahead of the driver's head, served as the centre console where the NDRT
204 was displayed.
205



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207
208 *Figure 2. A. The LS2N driving simulator. B. Areas of interest considered for the analysis of*
209 *gaze behaviour: the road scene in grey, the left (LM) and central (CM) mirrors in blue and*
210 *the tablet in orange.*
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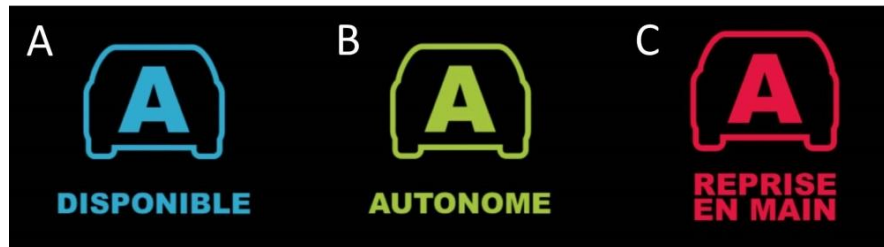
212 Gaze behaviour was recorded via a Smart Eye Pro eye tracker (version 5.9), which included
213 four cameras: two below the central screen and one below each lateral screen. Gaze and
214 vehicle data were recorded and synchronised at 60 Hz.
215

217 2.3. Procedure

219 2.3.1. Installation and instruction

220
221 First, participants were invited to settle in the simulator seat and the eyetracker calibration
222 was performed. Then, participants were informed about the operation of an automated SAE
223 Level-3 vehicle. They were asked to switch from manual to automated driving when the
224 automated system required it, using a touchscreen button on the tablet. A confirmation
225 pictogram was displayed (see Figure 3B). Then, participants could release the control of the
226 vehicle by removing their hands from the steering wheel and their feet from the pedals. In the
227 case of an unplanned TOR, a red pictogram associated with an auditory warning was
228 displayed. The drivers had 8 s to resume control of the vehicle, either by pressing a
229 touchscreen button on the tablet or by acting on the pedals (accelerator pedal threshold at 1%
230 of total possible depression, brake pedal threshold at 1 N) or steering wheel (torque threshold
231

232 at 1 N.m). During automated driving, participants were instructed to perform an NDRT. As
233 Shi & Frey (2021) indicated that participants primarily wanted to engage in reading, the task
234 consisted of reading aloud a text that scrolled automatically on the side tablet. The text was an
235 excerpt of the story of Tom Sawyer. Participants were asked to read the story as they would
236 read it for another person. After pretests, the scrolling speed was chosen to make the task
237 demanding enough that participants did not have time to look at the road.
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240
241 *Figure 3. Pictograms displayed on the HMI: A: autonomous driving available; B:*
242 *autonomous driving activated; C: take-over request (8s).*

243 2.3.2. Scenario

244
245 Prior to conducting the experimental trial, participants completed two familiarization trials.
246 The first allowed participants to test the transition between manual and autonomous driving 2
247 times. In the second training trial, they were asked to perform the NDRT in the autonomous
248 driving phase.

249 Then, the experimental trial was carried out. Participants drove on a 3-lane highway at 110
250 km/h, with moderate traffic, for 8 min before a critical unplanned TOR happened. They
251 started on a highway insertion ramp in manual mode. One minute after entering on the
252 highway, they were invited by the system to switch to automated mode. After 2 minutes of
253 automated driving, 5 minutes remained before the TOR. During that time, the task of the
254 participants (performing the NDRT or not) depended on the experimental condition (see
255 below). As soon as the scenario ended, all screens were switched off and the participants
256 reported their SA. This was performed on a touch tablet. Participants were asked to report the
257 vehicles they were aware of at the time of the TOR on a scheme representing the road scene
258 in top view. Their own vehicle and the obstacle were already placed, so they only had to place
259 other vehicles they had seen before the TOR.

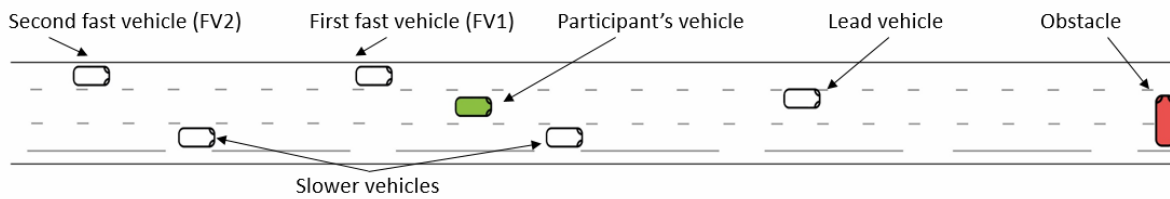
260 261 2.3.3. Unplanned critical takeover

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263 At the end of the experimental trial, participants had to regain control of the vehicle in a
264 complex critical situation (see Figure 4) that unfolded as follows:

- 265 (1) 5 min before the TOR, the participant's vehicle started to follow a lead vehicle with a
266 time headway of 3 s.
- 267 (2) 2 min before the TOR, the participant's vehicle and the lead vehicle began to move
268 into the centre lane to overtake two slower vehicles.
- 269 (3) 1 min before the TOR, two rapidly moving vehicles – travelling 2 s apart –
270 approached from behind in the left lane. They travelled at 120 km/h and started to
271 overtake the participant's vehicle. The first of these fast vehicles was called FV1 and
272 the second FV2. They were visible in the central and left mirrors 20 s before the TOR.

273 (4) At 1 s before TOR, the lead vehicle changed lanes to avoid a vehicle that had stopped
 274 across the right and centre lanes.
 275 (5) At the time of TOR, participants had only a partial direct view of the obstacle vehicle,
 276 because the lead vehicle was still changing lanes. The emergency TOR was delivered.
 277 If the NDRT was in progress, it was deactivated.

278 Participants had 8 seconds to resume control of the vehicle before reaching the obstacle (time
 279 to collision). To successfully intervene, participants could either brake and try to move
 280 between the two fast overtaking vehicles in the left lane or could change lanes after they had
 281 both passed. Alternatively, they could stop in the centre lane before reaching the obstacle.
 282



283
 284 *Figure 4: Critical case*
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286 Although the time to collision was 8 s at the moment of the TOR, drivers had less time to
 287 regain SA due to the movements of other vehicles. Indeed, FV1 disappeared in the blind
 288 spot 3.2 s (SD = 0.1) after the TOR. If participants did not detect the vehicle while it was
 289 visible in the mirrors, they were likely to initiate a lane change without being aware of the
 290 vehicle's presence; this would result in a collision or a late abortion of the manoeuvre. For
 291 the analysis of gaze behaviour after the TOR, we refer to this crucial 3.2-s period as the
 292 “critical phase”.

293 **2.3.4. Experimental conditions**

294 Participants were instructed to continuously monitor the road scene, except when they
 295 were asked to perform the NDRT. The session started with 1 min of manual driving,
 296 followed by 2 min of automated driving without any NDRT. The last 5 min of the trial
 297 depended on the experimental condition the participant had been assigned to (see Figure
 298 5):
 299

- 300 5):
- 301
- 302 • Full SA: No NDRT was required.
- 303 • SA_NDT: The NDRT was required only during the last 2 s before the TOR.
- 304 • NDT_SA: Participants had to perform the NDRT during the 5 min, except for during
 305 the last 2 s before the TOR.
- 306 • Full NDT: The participant had to perform the NDRT continuously up to the TOR.

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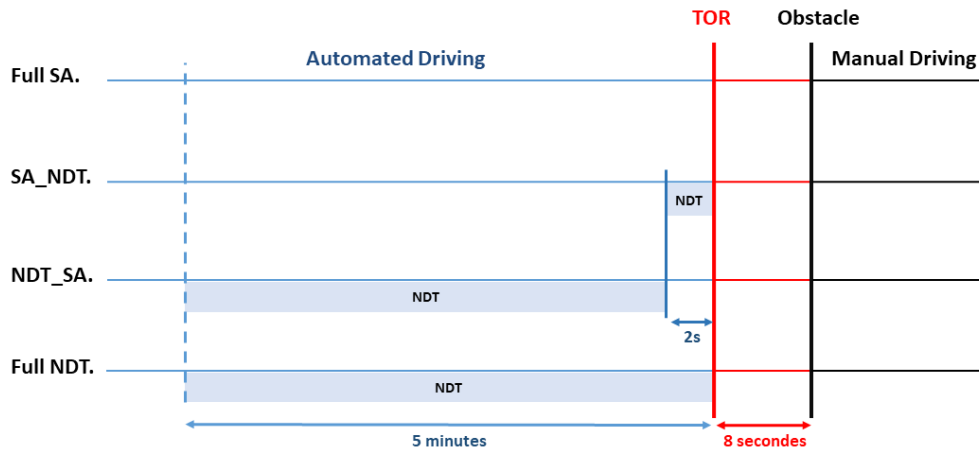


Figure 5. Timeline of the experimental conditions

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Participants were randomly assigned to one of the experimental conditions.

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3. Data Analysis

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The effects of the experimental conditions on the number of collisions and the number of times FV1 was reportedly perceived were analysed using chi-square tests. Because the number of times FV2 was reported was too low, Fisher's exact test was used.

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Gaze behaviour during the critical phase (post-TOR) was analysed by considering three areas of interest (AOIs): the tablet, the left and centre mirrors, and the road scene (see Figure 2B). For each participant, we analysed gaze data to extract fixations and saccades.

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First, the time between the TOR and the first fixation toward the road or the mirrors was calculated for each participant. Shapiro's test showed that the dataset was not normally distributed. Hence, a non-parametric method (Kruskal-Wallis) was used to assess the effect of the experimental conditions.

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Second, for each AOI considered independently, the numbers of participants who made at least one fixation at that AOI after the TOR were compared using the chi-square test.

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The proportion of fixation time spent on the different AOIs was also compared. For each participant, this period corresponded to the cumulative fixation time on each AOI, divided by the total fixation time during the critical phase. Since the dataset was not normally distributed, the Kruskal-Wallis test was used. Saccade time was not taken into account.

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Finally, the evolution of gaze distribution during the 3 seconds after the TOR was scrutinized. For each second during this period, the percentage of time spent on each AOI was calculated. As the dataset was not normally distributed, we used the Kruskal-Wallis test to compare the effect of the conditions on the mean percentage of time for each AOI at each second.

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4. Results

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Eighty-eight trials were performed in total, one for each participant. Of these, 45 resulted in a collision with another vehicle: 23 with FV1, 10 with FV2, and 12 with the obstacle. No collision occurred with the vehicles travelling in the right-hand lane.

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4.1. Effect of conditions on the occurrence of collisions

When considering the occurrence of collisions, a main effect of the experimental conditions was found ($\chi^2 = 8.50, p < .05$). Figure 6 shows that the percentage of collisions was higher in the Full_NDT condition (73% or 16/22 participants) than in the NDT_SA condition (59% or 13/22 participants). In turn, the NDT_SA condition resulted in more collisions than either the Full_SA or SA_NDT conditions (36% or 8/22 participants for each of the latter groups).

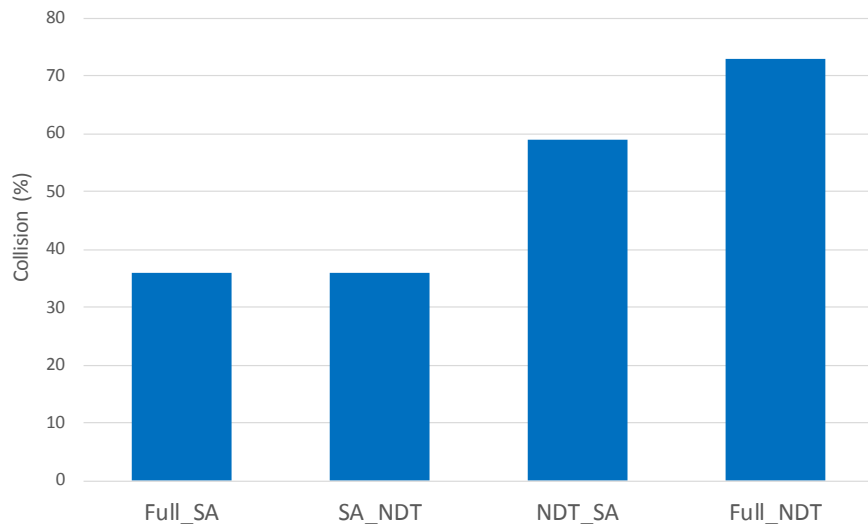


Figure 6. Percentage of participants who collided in each condition

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4.2. Effect of conditions on the awareness of the first vehicle

Since none of the participants attempted to avoid the obstacle from the right, only the fast vehicles in the left lane were relevant. FV2 was rarely reported by participants, as the distance made it relatively inconspicuous in the mirrors (4/22 participants for Full_SA, 6/22 participants for SA_NDT, 3/22 participants for NDT_SA, and 0/22 participants for Full_NDT). The results of the Fisher exact test ($p > .05$) did not show any effect of the conditions on drivers' awareness of FV2. By contrast, as shown in Figure 7, FV1 was often reported in the Full_SA and SA_NDT conditions (82% or 18/22 participants in both cases). It was reported less often in the NDT_SA condition (45% or 10/22 participants) and rarely (9% or 2/22 participants) in the Full_NDT condition ($\chi^2 = 32.267, p < .05$).

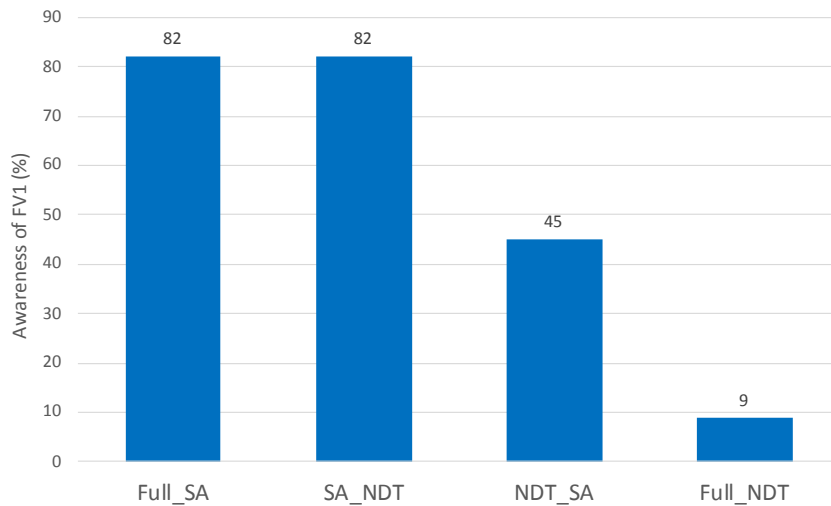


Figure 7. Percentage of participants in each experimental condition who were aware of FV1 at the moment of TOR

4.3. Effect of conditions on fixations during the critical phase after TOR

4.3.1. First fixation after the TOR on the road or the mirrors

Figure 8 shows a significant effect of the experimental conditions on the time of the first fixation to the road or the mirrors ($\chi^2 = 47,835$, $p < 0.05$). While almost all participants in the Full_NDT and SA_NDT groups looked at these AOIs at the time of the TOR or shortly thereafter, those in the SA_NDT and Full_NDT groups took more than a second on average to do so.

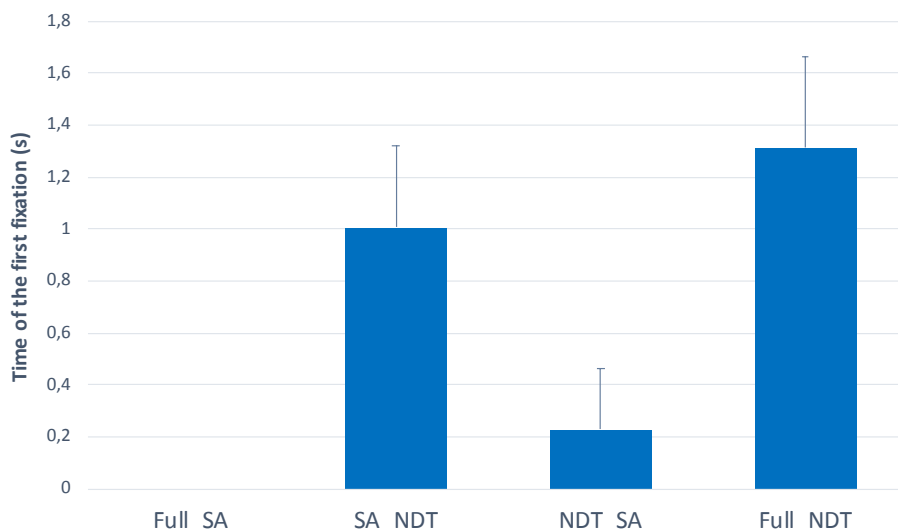
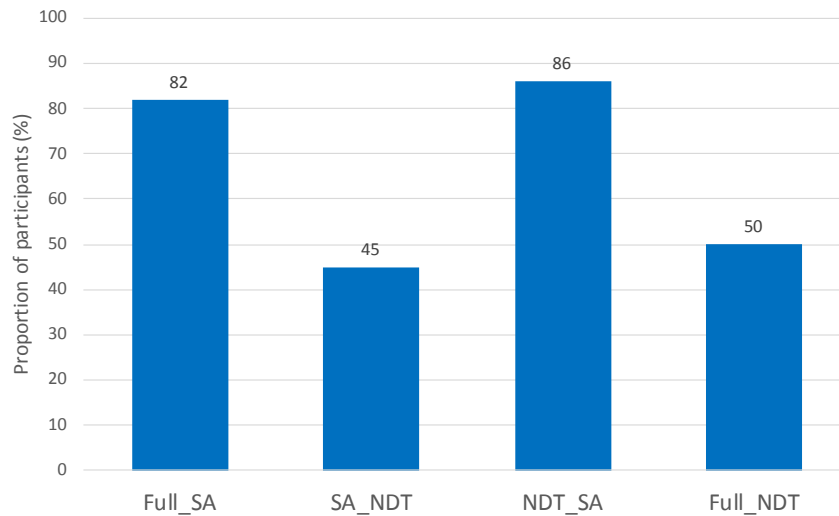


Figure 8. Mean time of the first fixation to the road or one of the mirrors after the TOR

4.3.2. Number of participants who looked at AOIs

More participants made fixations to the left and/or central mirrors in the Full_SA and NDT_SA conditions than in the Full_NDT and SA_NDT conditions ($\chi^2 = 13.149$, $p < 0.05$).

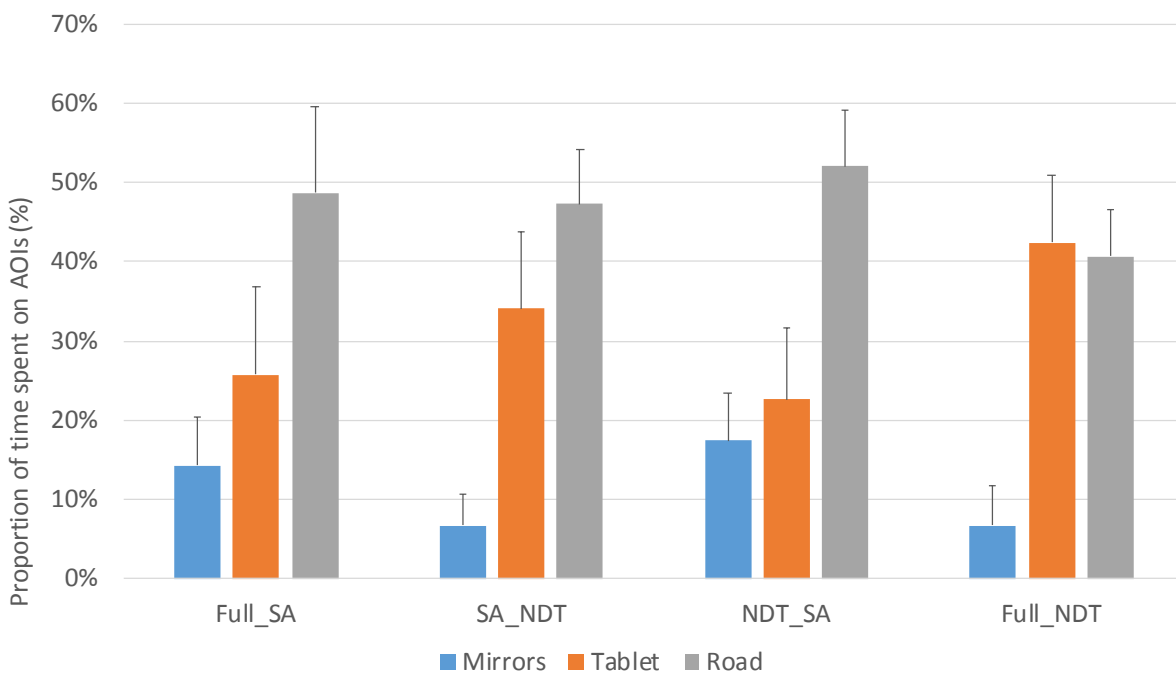
394 No significant effect was found for fixations towards the road or the tablet for the various
 395 experimental conditions (see Figure 9).
 396



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 398 *Figure 9. Percentage of participants in each condition who made fixations at the left and*
 399 *centre mirrors at least once*
 400

401 *4.3.3. Proportion of fixation time spent on AOIs*
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403 Figure 10 shows the proportion of fixation time spent looking at the three AOIs. Participants
 404 spent more time to look at the left and central mirrors in the Full_SA and NDT_SA conditions
 405 than in the Full_NDT and SA_NDT conditions ($\chi^2 = 17.35, p < 0.05$). Conversely, they
 406 spent more time looking at the tablet in the Full_NDT and SA_NDT conditions than in the
 407 Full_SA and NDT_SA conditions ($\chi^2 = 14.83, p < 0.05$). Time spent to make fixations at the
 408 road was not significantly different between the different conditions ($\chi^2 = 1.17, p = 0.328$).
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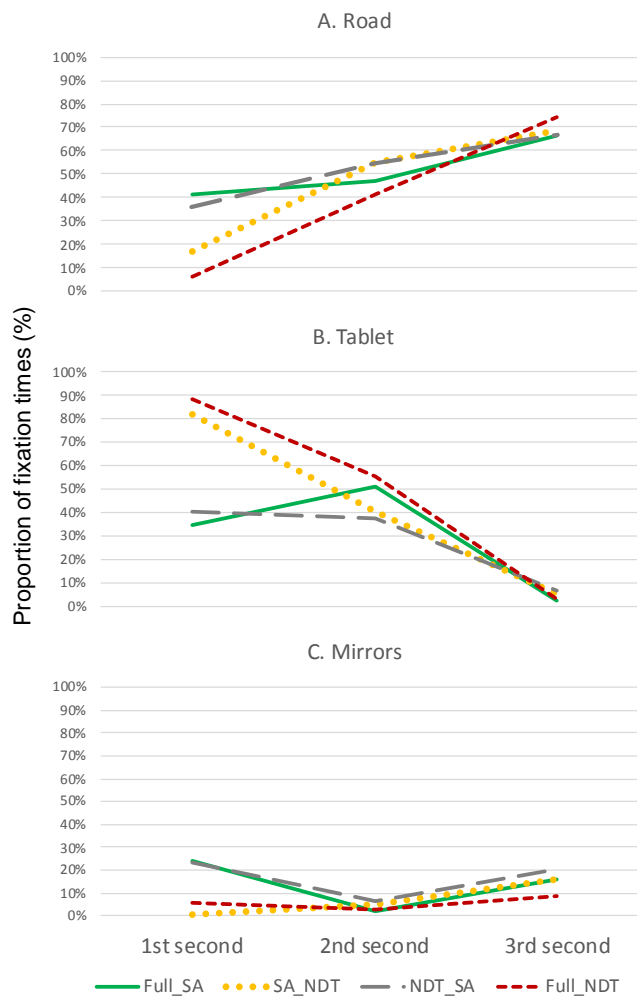


410
 411 *Figure 10. Influence of experimental condition on distribution of fixation during critical*
 412 *phase after TOR. (The three AOIs are depicted in Figure 2.B)*

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4.3.4. *Effect of conditions on the time spent each second on each AOI for seconds*

Figure 11.A represents the percentage of time spent looking at the road during each of the first 3 seconds following the TOR. An effect of the experimental condition is observed only for the first second ($\chi^2 = 32.077$, $p < 0.05$). The Full_NDT group spent significantly less time on the road compared to NDT_SA and SA groups. The SA_NDT group only differed from the Full_SA group. The same analysis was performed on the time spent looking at the tablet (see Figure 11.B). We also found an effect of conditions only for the first second ($\chi^2 = 42.824$, $p < 0.05$). The Full_SA and NDT_SA groups were significantly different from the Full_NDT and SA_NDT groups. Considering now the time spent on the centre and left mirrors (see Figure 11.C), again, the effect of the conditions was found only for the first second ($\chi^2 = 23.388$, $p < 0.05$), with the SA_NDT group showing significantly less time spent on the mirrors than the Full_SA and NDT_SA groups.



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Figure 11. *Percentage of time spent during the 3s-period following the TOR on A. the road, B. the tablet and C. the mirrors, depending on the experimental condition.*

437 5. Discussion

438

439 In this study, we manipulated the driver's ability to monitor the driving scene over a long
440 period or only during the 2 s preceding a TOR. By doing so, we were able to assess the
441 importance of being on-the-loop at the critical moment and thus being able to rely on
442 relatively elaborate SA. In other words, we investigated whether giving drivers 2 s before they
443 resumed control of the vehicle was sufficient to restore SA. To assess this, we asked drivers to
444 indicate whether they had been aware of vehicles in the driving environment just before the
445 TOR. Our results support the idea that 2 s of distraction did not impact SA if it was previously
446 adequate. In both the SA_NDT condition and the Full_SA condition, most drivers reported
447 being aware of the vehicle coming fast in the left lane. However, recovering the ability to
448 monitor the driving scene just prior to the TOR was useful for drivers who had been distracted
449 in the preceding minutes. Drivers in the NDT_SA condition reported the presence of FV1
450 more often than those in the Full_NDT condition. This result suggests that stopping the
451 NDRT 2 s before the TOR allowed the development of a degree of SA, which partially
452 compensated for the lack of a consolidated mental model of the situation.

453

454 Having good SA does not necessarily imply a smooth takeover. Indeed, the critical situation
455 set up in this study was really difficult to negotiate, which explains the high number of
456 collisions. The role of the NDRT in the occurrence of those collisions has been
457 demonstrated. However, the complexity and kinematics of the driving scenario have been
458 identified in the literature as one of the factors responsible for the reduction of take-over
459 quality (Gold et al., 2016; Louw, Markkula, et al., 2017; Radlmayr et al., 2014; Scharfe et
460 al., 2020; Zhang et al., 2019). Another essential point is the taker-over time budget in
461 critical situations. Damböck & Bengler (2012) tested time budget of 4 s, 5 s, 6 s and 8 s. They
462 found that drivers crashed more often in all time budgets except for the 8 s condition
463 compared to manual driving. Gold et al., (2013) also found a better take-over performance for
464 a 7s time budget than for a 5s time budget. In Mok et al. (2017) drivers could handle a critical
465 situation with a take-over time between 5s and 8s whereas they were practicing an active
466 NDRT. Our results showed that even with an 8s time budget and a good SA, drivers could
467 have difficulty regaining vehicle control in a complex situation. Indeed, 1/3 of drivers had
468 a collision in the Full_SA and SA_NDT groups, even though they reported the presence of
469 the most dangerous vehicle in the left lane. In situations similar to the critical case we
470 used, returning control of the vehicle to the driver would not be the best solution. It would
471 probably be better for the automated system to decide, based on the assessment of the
472 criticality of the situation, to perform emergency braking rather than to issue a TOR.

473

474 However, the quality of the takeover was consistent with the level of elaboration of SA.
475 Drivers in the Full_SA and SA_NDT groups passed the critical case with the same level of
476 success (64%), which was notably better than in the NDT_SA group (41%) – which in turn
477 was better than the performance of the Full_NDT group (27%). Thus, just as for SA, drivers
478 benefited from having been able to supervise the driving scene well before the TOR. The final
479 2 s were not sufficient to obtain a good quality of takeover if SA was low to begin with.

480 Previous studies have shown that the level of mental load associated with an NDRT
481 performed at the time of a TOR was not predictive of the takeover quality (Bueno et al., 2016;
482 Marti et al., 2021). This point does not fit well with the idea that the more distracting an
483 NDRT is, the more difficult takeover will be. The main difference between those studies and
484 ours is that we manipulated the duration of engagement in the NDRT before takeover, rather
485 than its difficulty level. In addition, Marti et al. (2021) showed that the only determinant of

486 successful critical control was whether the driver was looking at the road rather than a
487 peripheral NDRT at the time of the TOR, regardless of the difficulty of the NDRT. This
488 finding might have reflected in the outcomes of our experiment if participants who looked at
489 the tablet at the time of TOR (SA_NDT and Full_NDT) had shown greater difficulty in taking
490 over than did undistracted drivers (Full_SA and NDT_SA). This was not the case. Instead, the
491 analysis of gaze behaviour after the TOR showed a perseverance effect, with drivers in the
492 SA_NDT and Full_NDT conditions spending more time looking at the tablet and less time
493 checking their mirrors. This is consistent with the observation that the first fixation to the road
494 of the mirrors was performed about 1 s later in those conditions. The drivers who were not
495 performing the NDRT at the time of the TOR, even if they had spent about 5 min doing it
496 before (NDT_SA group), did not take significantly more time to look at the road or the
497 mirror. Additional analyses were conducted to examine in more detail the evolution of gaze
498 distribution during the seconds after the TOR. They showed that the perseverance effect
499 lasted only about 1 s. This is consistent with Louw, Madigan, et al. (2017) who observed that
500 out-of-the-loop drivers spent less time looking at the road centre during the first second after
501 an unexpected alert TOR. In our case, it appears that participants performing the NDRT kept
502 on looking at the tablet even though only a pictogram requesting to takeover was displayed on
503 it. The warning on the centre console could be a source of distraction, whereas the driver
504 should pay full and immediate attention to the reconstruction of SA to ensure the success of
505 the takeover. This suggests that avoiding the display of information on the centre console
506 during a TOR (e.g., blanking the screen) in order to discourage drivers from looking at
507 information on the device would lead to better performance. This hypothesis could be tested
508 in future studies.

509
510 That said, the perseverance at looking at the tablet did not result in increased collisions in the
511 SA_NDT condition, probably because drivers were aware of overtaking vehicles before
512 performing the NDRT. Taken together, the results suggest that continuous – or at least very
513 frequent – monitoring of the road scene is essential for building Level 3 SA, according to
514 Endsley's terminology. Level 3 requires developing a mental model of the situation that
515 allows anticipating its future state. The late disengagement from an NDRT may be sufficient
516 to correctly perceive the immediate environment (SA Level 1); however, it may be
517 insufficient to consider the dynamics of the situation. If the TOR intervenes while the driver is
518 engaged in a task on the central console, this can lead to a form of perseverance in looking at
519 the display. However, this perseverance was less critical to the success of the takeover than
520 having a sufficiently elaborated SA in our use case.

521
522 Some studies have explored solution to help the driver to rebuild SA during TOR. For
523 instance, Yousfi (2018) tested blind spot warning devices during takeover. She found that
524 the use of the blind spot detector reduced the collision rate with a vehicle in the left lane.
525 White et al. (2019) proposed a “top-down” guidance check after the emergency TOR;
526 drivers who had this system glanced more at their mirrors than drivers without. In the
527 same vein, Carsten & Martens (2019) advised a set of design principles to improve the
528 human-machine interface for automated cars.

529 530 **6. Conclusions**

531
532 In our study, we manipulated the drivers' engagement in a reading NDRT to prevent or
533 allow them to build and maintain SA. We have shown that as long as SA was adequate,
534 drivers were able to successfully manage the TOR even if they have been distracted for a
535 short period just before the TOR. Two seconds of NDRT did not degrade SA enough to

536 impair take-over quality. In future work, it would be interesting to further manipulate the
537 duration of distraction periods prior to the TOR to better understand from what time point
538 distraction impacts Level 3 SA. Conversely, it would be interesting to reproduce the
539 experiment by increasing the time given to drivers to rebuild SA in the NDT_SA
540 condition.

541
542 Participants engaged in the NDRT at the time of the TOR exhibited different visual
543 patterns during the first second of the takeover, with more time spent on the display and
544 less time spent at recovering SA (i.e., looking at the road and checking the mirrors). This
545 raises the question of the best design strategy to inform the driver of a need to regain
546 control without delivering a visual alert that may keep the driver's eyes away from the
547 road scene. Driving aids guiding the gaze towards the important elements to be taken into
548 account could even be useful.

549
550 The concept of SA appears central in current issues about vehicle automation. The
551 question of how to help drivers to maintain or restore sufficient SA has not yet been
552 definitely answered. Our results confirm the idea that particular effort must be made by
553 designers to restore a good level of SA quickly when the driver is out-of-the-loop. Further
554 work is needed to better identify the behavioural markers of SA, for example in terms of
555 mirror-checking routines or sequences of actions using the vehicle's controls. To
556 conclude, we refer to Louw et al. (2015), who stated that "until there is an effective strategy
557 to help drivers regain situation awareness during the resumption of control from Highly
558 Automated Driving, they should be encouraged to remain in the driving loop".

559
560

561 **Conflict-of-Interest Statement:**

562 The authors declare that they have no conflict of interest.

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