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DOI
10.1038/s41598-025-04796-6

Publication date
2025

Document Version
Final published version

Published in
Scientific Reports

scientific reports

Check for updates

OPEN

Predictors of long-term knowledge retention in the driver theory test

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To obtain a driver's licence, one must successfully complete a practical driving test and a theory test. Although the theory test is widely regarded as an important element of driving competence, little is known about the predictors of theory test performance, and in particular the extent to which the acquired knowledge is retained over the years. All individuals who passed a car theory test in the Netherlands between November 2019 and October 2023 were invited to complete a questionnaire, which included a retention test (i.e., a representative retake test) consisting of 20 items not used before. The results based on 50,857 respondents revealed that those with a lower level of education exhibited lower performance on the retention test. Moreover, respondents who took a course with an instructor, an approach mostly used by those with a lower level of education, had a relatively high likelihood of passing the official car theory test on the first attempt. It was also found that the extent to which knowledge increased or decreased over the years was item-dependent, a pattern possibly explained by whether the test item measures functionally relevant driving experiences or if it primarily assesses isolated rules. The results of this study are relevant for training institutes and policymakers.

Worldwide, when someone wants to obtain a driver's licence to independently participate in road traffic, they must typically first successfully complete both a theory test and a practical driving test. The current article focuses on the knowledge retention of a driver's theory test, a subject that is under-researched in the scientific literature. Although nearly every driver has completed a theory test, published knowledge about the effect of the theory test in general and, in particular, knowledge retention of theory tests, remains scarce.

A number of authors have previously performed an item analysis of the theory test content[1,2], or examined gender differences in test scores[3,4], yet without examining the validity of the test. Regarding validity, Maag et al.[5] found that accident involvement was higher among drivers (n = 111,500) who needed more than one attempt to pass the theory test compared to those who passed on the first try. However, this study did not clarify what possible covariates, such as education level or type of test preparation, were associated with this relationship. More recently, it has been found that people who had scored higher on the test made slightly fewer steering errors during training sessions in a driving simulator (r = −0.12, n = 804[6]). Sundström[7] found weak correlations between the score on the theory test and the performance in the practical driving test (n = 1,791), with the strongest correlation being with competence deficiency in traffic behaviour (r = −0.11). The consistency of these correlations across studies suggests a meaningful yet modest relationship between theoretical knowledge and driving performance. However, the mechanisms of this relationship remain underexplored. Finally, a UK study found that women generally spent more time preparing (14.8 h) than men (12.3 h)[[8], Table D17] ($n \approx$ 36,000). The most commonly used materials were books, as well as websites and interactive multimedia products. Only 0.5% reported not using any materials during their preparation for the theory test. This highlights the importance of preparation methods, yet leaves open the question of how different approaches might relate to long-term knowledge retention.

A key assumption underlying the theory test is that knowledge of traffic rules and adherence to these rules contribute positively to road safety[9]. An associated assumption is that once a person passes the practical test, their driving experience will help them retain the theoretical knowledge. This assumption is reflected in the fact that the theory test certificate expires if the practical test is *not* passed within a certain period of time, whereas once the practical driving test is passed, the theory test remains valid for one's entire driving life. For example, in New South Wales, Australia, the theory test certificate is valid for up to five years[10], in the Netherlands, the theory test is valid for up to 1.5 years[11], whereas in Sweden, candidates must pass the practical test within four months of passing the theory test[12]. Additionally, in more exceptional cases, a re-test may be required, for example, when the driver's licence has been revoked due to serious offences (e.g., The Netherlands[13,14], UK[15]) or when it has not been renewed for a long time (e.g., Queensland, Australia[16], New Zealand[17]). Given this assumption, it becomes important to assess whether drivers retain their theoretical knowledge over time.

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A related question concerns how candidates should practice for the theory test to not only pass but also retain the knowledge in the long term. In the Netherlands, there is a concern about the increasing availability of crash courses designed to prepare candidates for the theory test in a short period of time. While these courses may help individuals pass the tests, they may reduce retention of the material compared to spaced learning approaches[18]. Vlakveld[18] specifically examined driving theory acquisition and found that distributed practice led to better performance on delayed tests compared to massed practice, consistent with broader research on the spacing effect in learning[19]. Some driving schools and specialised companies offer theory lessons with in-person instructors[20]. Examples are group-based classroom sessions where an instructor explains traffic rules and strategies for answering questions correctly[21–23], weekend courses[24–26], or personalised one-on-one instruction for those needing extra support[27–29].

Neurobiological research suggests that the brain conserves energy by reorganising memories and discarding irrelevant ones, especially during sleep[30]. Strong emotional experiences can facilitate memory consolidation, while memories that lack (emotional) relevance are more prone to decay[31]. This is supported by a meta-analysis examining 69 studies across various domains by Wang et al.[32], which found that not using acquired knowledge leads to knowledge decay.

These observations are consistent with literature on the distinction between declarative knowledge (knowing what something is, such as specific facts and concepts) and procedural knowledge (knowing how to perform certain tasks). Literature indicates that when a behaviour is first learned by following explicit rules, the learner actively recalls those rules, which represent a form of declarative knowledge[33]. This can become skilled behaviour or procedural knowledge when operationalized through experience[34]. Failure to operationalize static, learned rules dynamically through practice would imply that the theory is not internalized and can therefore more easily be forgotten, whereas procedural knowledge is remembered unconsciously. These conceptualizations further relate to the notion of *schemata*, i.e., mental models or organised patterns of past experiences[35,36]. It has been found that drivers tend to recall what they expected to happen during a recent trip, rather than what actually happened, which suggests that they heavily rely on mental models shaped by past driving experiences[37,38]. In the same vein, it can be hypothesised that over time, traffic rules once learned for a theory test are reorganised into these mental models, allowing the theoretical knowledge to be reinforced (or even improved) through experience. However, information that is rarely encountered or harder to integrate, such as rare traffic signs or isolated traffic rules, is likely to be forgotten over the years (see also[39] for a very long-term retention study that shows that forgetting can be a continual process of several years).

So far, there is limited understanding of how well theoretical driving knowledge is retained over time and how different preparation methods influence this retention. This study aimed to fill this gap by inviting nearly one million people, resulting in more than 50,000 responses, to complete a specially developed short version of the official car theory test online. Our interest was in discovering the extent to which the time since completing the official car theory test influenced the retention of the knowledge of the various test items, and to what extent this linked to the type of preparation for the official car theory test. Drawing from the theoretical framework presented above, we hypothesized that preparation methods would be significantly associated with retention test performance, with time since the official car theory test being an important mediating factor as well.

Methods

A questionnaire was developed in cooperation with I&O Research, a market research agency, which was awarded the public tender. Internal data were provided under application number A2311 1926. Informed consent was obtained from all subjects as all participants were fully informed about the nature and goal of the study, the consequences of their participation, the anonymity of their answers, and the data handling procedure prior to participating, via an invitation email. They had the opportunity to retract their information at any given moment as per GDPR. The analysis of the results from this questionnaire was the topic of this study. This study was approved by the TU Delft HREC (approval number 4511), thus all methods were performed in accordance with the relevant guidelines and regulations. The questionnaire included demographic questions, questions about the respondents' preparation for the official car theory test, and a retake theory test, hereafter referred to as the retention test. This retention test consisted of questions provided by the Theory Division of the Dutch Central Office of Driving Certification (CBR) and was based on questions that were in the official car theory test. However, they were realistic and met the characteristics of the official car theory test as administered in the Netherlands.

Questionnaire design

The questionnaire consisted of 13 multiple-choice questions, in Dutch. For the current paper, the Dutch text from the questionnaire has been translated into English. The questionnaire contained the following introductory text: "*In this questionnaire, we will ask you questions about your preparation for the car theory test. In the second part of the questionnaire, you will take a mock theory test for a category B driving licence. This is not a full official test but a reflection of what a real test might look like. There will be correct and incorrect answers.*"

The first part (Q1–Q7) consisted of questions about how respondents prepared for the official car theory test, specifically:

Q1. *How did you prepare for the car theory test? (multiple answers possible)*, with response options: (a) Self-study, (b) Half-day course with a live instructor, (c) Full-day course with a live instructor, (d) Multi-day course with a live instructor, (e) No preparation, (f) Other, namely, (g) I don't know. When only (e) was selected, the questionnaire continued with Q7. When the respondent indicated engaging in self-study (answer a) or spending more than one day (answer d), the questionnaire continued with Q2; if not, the questionnaire continued with Q6.

Q2. *How much time did you spend preparing for the car theory test? If you don't know exactly, please make the most accurate estimate possible.* The response options were: (a) 0–24 h, (b) 1–3 days, (c) 4–7 days, (d) 1–3 weeks, (e) 3 weeks or more. When answer (a) was selected, the questionnaire continued with Q4.

Q3. *How much time did you spend daily preparing for the car theory test? If you're not sure, please provide the most accurate estimate possible.* The response options were: (a) Less than 15 min, (b) 15–30 min, (c) 30 min to an hour, (d) One to two hours, (e) More than two hours.

Q4. *Where did you prepare for the car theory test? (multiple answers possible)*, with response options: (a) At home, (b) At the theory test provider, (c) Outside the home in a quiet place (e.g., school, work, or library), (d) At another location. If only one response was selected, the questionnaire continued with Q6.

Q5. *Where did you spend the most time preparing? If you are not exactly sure, please make the most accurate estimate possible.* The response options were: (a) At home, (b) At the theory test provider, (c) Outside the home in a quiet place (e.g., school, work, or library), (d) At another location.

Q6. *Which of the following tools did you use to prepare for the car theory test? (multiple answers possible)*, with response options: (a) Theory (e-)book, (b) Practice tests, (c) Video lessons, (d) Online portal with study material (including summaries), (e) Other, namely, (f) I did not use any tools.

Q7. *How much time was there between completing your preparation and taking the car theory test?* If you are not exactly sure, please make the most accurate estimate possible. (a) 0–24 h, (b) 24–48 h, (c) 48 h or more.

The second part (Q8–Q12) consisted of questions about car usage and demographic information thought to covary with knowledge retention and driving performance:

Q8. *How many kilometres have you driven in the past 12 months, approximately?*, with 9 mileage categories (a–i) as well as the response options: (j) I have not driven myself, and (k) I really don't know.

Q9. *How often have you driven, on average, in the past 12 months?*, with response options: (a) Every day, (b) 4–6 days per week, (c) 1–3 days per week, (d) Once a month, (e) Less than once a month, (f) Never.

Q10. *What is your gender? Please enter the gender that is listed in your passport or on your ID card.* Response options were: (a) Male, (b) Female, (c) X (gender neutral).

Q11. *What is the highest level of education you have pursued? This education does not need to be completed. Are you a student? Then enter the program you are currently enrolled in.* The response options were as used by[40] and ranged from (a) No education to (g) University master (see appendix A for all answer possibilities). Response options (a)–(d) were labelled as 'lower', and response options (e)–(g) as 'higher'. Note that we labelled based on the level of education, not on the extent of progress made within the educational trajectory. For example, high-school VWO (e) is typically followed by a BSc (f), and MSc (g), but all three were classified as 'higher'.

Q12. *In which province do you live?*, with 12 response options.

The above 12 questions were followed by the 20-item retention test (T1–T20), with the following introduction: "*You are now about to take the modified car theory test. Take a moment to settle in and maybe grab a drink. This test consists of 20 questions. In some of the questions, you will see a white learner's car. You should imagine that you are the driver of this car. If you don't know the answer right away, you can leave it blank. You can navigate back and forth between the questions. Note! After answering the last question, you will no longer be able to go back. When you're ready, click through to the next page. Best of luck!*".

The 20 questions of the retention test were tailored to represent the knowledge and insight part of official car theory tests, which normally consist of 40 questions (As of April 7th 2025, this has become 50 questions[41], with knowledge, insight, and [a new form of] hazard perception questions combined). The number of questions was reduced to increase the willingness of the candidates to complete the study. Answering the questions of the retention test was not mandatory. Consistent with an official car theory test, the 20 questions of the retention test were derived from different subjects used by CBR: (S1) *road usage*, (S2) *right of way*, (S3) *special road types/road users*, (S4) *safe driving with the vehicle and responding in emergency situations*, (S5) *traffic signs*, (S6) *responsible traffic participation and eco-friendly driving*, (S7) *traffic laws* and (S8) *vehicle knowledge*[42]. Subject 8 (vehicle knowledge) did not feature a question in the retention test of the present study.

The questionnaire ended with the following question:

Q13. *You have just taken the test. In what kind of environment did you take this test? If your environment is not listed, choose the one that is the closest.* The response options were: (a) At home, (b) On the go (for example, in public transport or as a passenger in a car), (c) At my workplace, (d) In another quiet place, and (e) In another busy place.

The respondents were presented with a closing statement offering the option to be presented with their test result.

Data acquisition

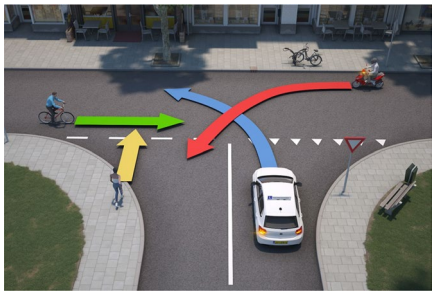
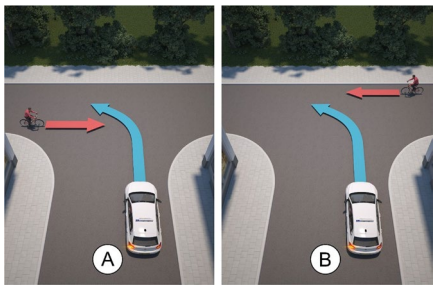
The distribution of the questionnaire and data collection was handled by I&O Research. Between mid-January 2024 and early March 2024, emails were sent in batches to all 892,367 individuals who had passed their car theory test between November 1, 2019, and October 31, 2023. The email mentioned that the study involved filling out a questionnaire and taking a mock theory test to help improve future test preparation materials. It was emphasised that participation was voluntary, and would not impact the respondent's driving licence. A contact address for asking questions was provided as well.

The questionnaire could be completed up until March 21, 2024. The vast majority of respondents, 97.5%, completed the questionnaire during the period from February 14, 2024, to March 11, 2024. A 'soft launch' of the questionnaire took place in mid- and late-January with a limited selection of recipients. No reminder emails were sent.

The responses were combined with the following information from the CBR:

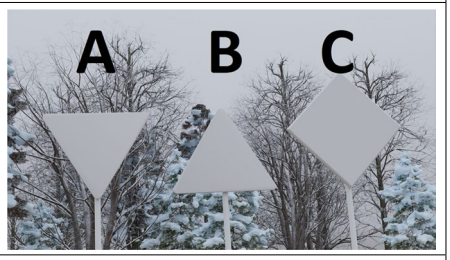
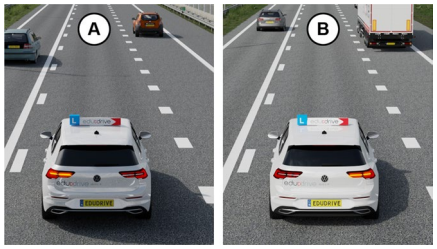
C1. Age of the respondent in full years (as measured on December 12, 2023, during the preparation phase of the study).

Subject	Question	Corresponding image
S1: Road usage	T6. From what distance from a pedestrian crossing are you allowed to park? (a) From 3 m distance (b) **From 5 m distance** (c) From 12 m distance	N/A
	T8. You park here. Is that allowed? **(a) Yes** (b) No	
	T16. What is your maximum allowed speed here? (a) 80 km/h **(b) 100 km/h** (c) 130 km/h	
Continued		

Subject	Question	Corresponding image
S2: Right of way	T9. Who must you give way to? (a) Only the moped (b) Only the moped and the bicycle **(c) The moped, the bicycle, and the pedestrian**	
	T12. Must you give way to the cyclist? **(a) Yes** (b) No	
	T19. In which situation is the learner car allowed to go first? **(a) Situation A** (b) Situation B (c) Both situations	
	T20. Who may go first? **(a) Car** (b) Pedestrian	
Continued		

Subject	Question	Corresponding image
S3: Special road types, road users, and manoeuvres	T1. You want to turn around at the intersection. Who do you have to give way to? (a) Only drivers of motor vehicles (b) Only drivers **(c) All road users**	
	T14. The white van is parked. Must you give way to the oncoming car? (a) Yes **(b) No**	
S4: Safe driving and responding to emergencies	T3. Visibility is poor due to heavy rain. Which lights are you allowed to use? (a) High beam (b) Rear fog light **(c) Front fog light**	
	T15. You arrive first at a serious accident. What do you do first? (a) Provide first aid (b) Call emergency services via the emergency number 112 **(c) Turn on warning lights**	
	T17. From what height is a child allowed to ride without a child restraint system? (a) 1.20 m **(b) 1.35 m** (c) 1.50 m	

Continued

Subject	Question	Corresponding image
S5: Traffic signs and signals	T2. How many lanes will this road soon have? (*numeric entry*) **3**	
	T7. At which of these snow-covered traffic signs must you give way? **(a) Sign A** (b) Sign B (c) Sign C	
	T11. You want to change lanes. In which situation is this allowed? (a) Only in situation A (b) Only in situation B **(c) In situation A and B**	
S6: Responsible traffic participation and eco-friendly driving	T4. Do you have more grip on the road surface with over-inflated tyres? (a) Yes **(b) No**	N/A
	T10. On which road surface must you account for a longer braking distance? (a) On a dry road surface **(b) On a wet road surface** (c) The road surface does not affect the length of the braking distance	N/A
	T13. You are merging and want to overtake the lorry immediately. Are you allowed to move to the left lane straight away? (a) Yes **(b) No**	
	T18. You are driving on the motorway and want to move to the middle lane. What must you consider? (a) Only that the van is going to merge into the middle lane (b) Only that you have sufficiently passed the motorcyclist **(c) That you have sufficiently passed the motorcyclist and that the van is going to merge into the middle lane**	

Continued

Subject	Question	Corresponding image
S7: Legislation	T5. What is the permitted maximum weight of the van if you want to drive it with a category B licence? (a) 2500 kg **(b) 3500 kg** (c) 7500 kg	
S8: Vehicle knowledge	No question included	N/A

Table 1. The 20 questions of the retention test, with the subject (S1–S8), question number (T1–T20) representing the order in which the questions were posed, and corresponding image. The correct answer is listed in boldface. Sources of images: Smit Rijschoolservice, LENS Verkeersleermiddelen, and Verjo B.V.

C2. Number of official car theory tests taken. Here, "1" meant the respondent passed on the first attempt, "2" on the second attempt, etc. Since only people who had passed their theory exam were invited, the minimum value was 1. The maximum value was 10, which represented '10 or more'.

C3. Time interval between passing the official car theory test and taking the questionnaire. This interval was made available in quarters (i.e., 0.25 years), which was done to reduce the traceability of the candidates' identity in light of internal privacy standards. The minimum value was 1 quarter, corresponding to the period 3 to 5 months, and the maximum value was 17 quarters.

C4. Number of practical driving tests taken. The minimum number was 0, and the maximum number was 10, which represented '10 or more'.

Data preprocessing

In total, 52,157 persons out of 892,367 recipients completed the questionnaire, a 5.8% response rate.

We redistributed responses labelled as *Other*, *namely* for questions Q1 and Q6, as some respondents had misunderstood the question. Specifically, for Q1, 4,670 of 52,157 respondents (9.0%) chose *Other*, *namely*, though many explanations they provided could be classified as *Self-study* (e.g., watching YouTube videos, reading websites, or using mobile apps). After re-coding, 856 respondents (1.7%) remained in the *Other*, *namely* category. For Q6, regarding types of resources used, a similar approach was used: responses such as "YouTube" or "TikTok" were reassigned to *Videos* while answers such as "theorie toppers", "online course", "app", and "Google" were re-categorised under *Online portal*. This reclassification reduced the total *Other*, *namely* responses from 2,537 (4.9%) to 1,647 (3.3%).

Respondents who completed the retention test in less than 2 min or more than 20 min were excluded from the analysis. After applying this filter, the final dataset consisted of 50,857 respondents. The 2-minute threshold was used because extremely fast responses are more likely to be random[43], see also Fig. 1. The threshold of 20 min was used because a long test duration could signal that the respondent left the test and continued it later. It was reasoned that such responses may be less valid and should be excluded. Furthermore, the 20-minute threshold was used to maintain approximate comparability with the official car theory test, which allows roughly 24 min for 40 questions[44]. We set the threshold somewhat generously because there was no time limit on the retention test; participants could take as much time as they wanted. The correlations between test completion duration and external variables were generally weak, with the exception of age, which showed a moderate positive correlation of 0.31 ($p < 0.001$, $n = 50{,}857$).

Analysis

The aim of our study was to investigate how preparation methods, time passed since the official car theory test, and respondent demographics were related to the score on the official car theory test and the score on the retention test.

We conducted a descriptive analysis by reporting the percentage of respondents who passed the official car theory test on the first attempt (C2) for all response options across the 13 questionnaire items (Q1–Q13). Additionally, we presented the mean score on the retention test, supplemented by the percentage of respondents with a high level of education, as determined by Q11.

To better understand the patterns of self-selection, we also examined how personal characteristics and average scores on the retention test were related to the number of attempts needed to pass the official car theory test (ranging from 1, 2, 3, up to 10 or more attempts). Because multiple variables simultaneously predicted the score on the retention test, a linear regression was conducted to better understand the unique contribution of these predictors.

Finally, we attempted to qualitatively assess what type of retention test items saw a decline in scores over the years and which types of items either remained stable or improved over time. To do this, we compared item scores on the retention test for respondents in Quarter 1 (i.e., respondents who successfully completed their official car theory test less than 3 to 5 months ago) with Quarter 16 (i.e., respondents who successfully completed their official car theory test 48 to 50 months ago). Quarter 17 was not included here because there were relatively few respondents in this bin.

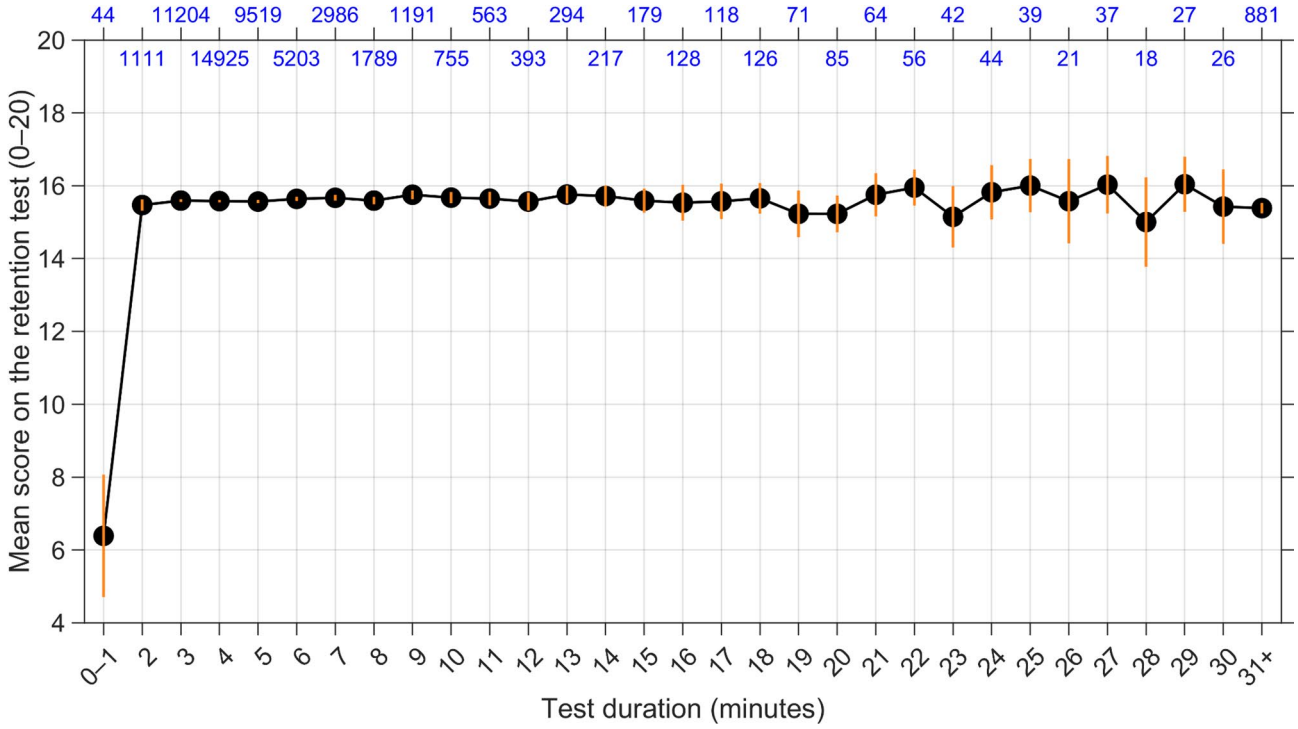


Fig. 1. Mean score on the retention test versus the time taken to complete the retention test (rounded to the nearest minute). Also shown are corresponding sample sizes (blue numbers on top) and 95% confidence intervals calculated by assuming a normal distribution (orange vertical lines). Completing the test extremely quickly (in 0–1 min) is associated with poorer performance on the test.

In presenting the results, we used statistical tests only sparingly. This is because our sample size was large and the CIs narrow. This can be observed, for example, in Figs. 2 and 3 of the Results section, where 95% CIs are presented after dividing the data into 17 groups based on the number of quarters since the official car theory test (variable C3). It is evident that even after partitioning into many subgroups, the CIs often do not overlap, even for adjacent quarters. The high statistical power of the sample is also demonstrated by the fact that even a weak correlation of $r = 0.02$ is statistically significantly different from 0 ($p = 6 \times 10^{-6}$).

Results

Descriptive statistics

The descriptive statistics in Table 2 reveal that respondents with a higher level of education (Q11) were more likely to pass the official car theory test on the first attempt compared to those with a lower education level (61.2% vs. 44.8%). Also on the retention test, respondents with a higher education level scored higher, 15.88 versus 15.10 correct answers out of 20. In comparison, the overall mean score on the retention test was 15.59 out of 20 ($SD = 2.11$, with 15.8% of respondents having a score of 13 or lower, and 18.6% having a score of 18, 19, or 20). Since education level provides a relatively strong explanatory factor, we have added this information to Table 2 for all responses.

Regarding preparation method (Q1), most respondents (57.8%) only used self-study to prepare, while a large group (22.7%) did no self-study and only took a course with an instructor. Only a small portion of respondents (1.1%) reported not preparing at all. Self-study was preferred by those with a higher level of education (73.2% are highly educated), while only taking a course was a method preferred by those with lower education (47.6% of this group is highly educated).

The duration of self-study (Q2) was longer for respondents who did not pass the official car theory test on their first attempt. One explanation is that failing the official car theory test implies that more study time is needed to pass and/or that respondents with a lower level of education need to study more in order to obtain the required level of knowledge. No clear connection could be identified between self-study duration (Q2) and retention test scores. Regarding the intensity of the self-study (Q3), studying for longer periods per day was a strategy commonly used by those with higher education levels.

The methods used for self-study (Q6) are diverse, but most respondents used practice tests (76.1%) and a theory book (62.5%). Videos (35.1%) or online training portals (37.2%) were also frequently used. Continuing to study until the last moment, rather than stopping preparation a few days before the official car theory test (Q7), was associated with a higher education level and a greater likelihood of passing the official car theory test.

The pattern of mileage and car usage (Q8 & Q9) in relation to official car theory test scores is complex. Higher-educated people drive less than those with lower education levels, consistent with the idea that higher-educated individuals are often still studying, while those with lower education levels may use the car for work-

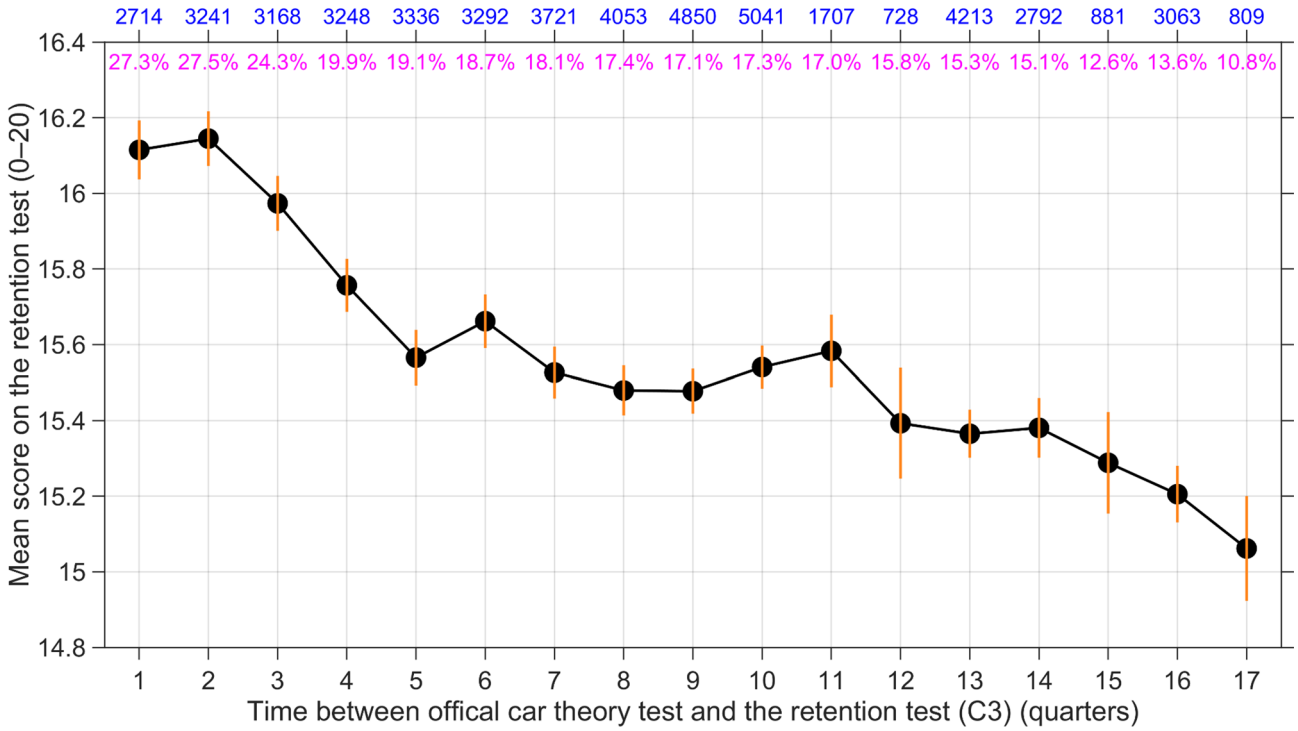


Fig. 2. Mean score on the retention test versus the time between passing the official car theory test and the current retention test as part of the questionnaire. Also shown are corresponding sample sizes (blue numbers on top), percentage of respondents with a score of 18 or higher (magenta numbers below that), and 95% confidence intervals calculated by assuming a normal distribution (orange vertical lines). Fluctuations in sample size and performance might be attributable to the effects of COVID-19 lockdowns. No official car theory tests were held in the Netherlands during the periods from March 16 to May 12, 2020, and from December 15, 2020, to April 27, 2021.

related purposes (as also described by Kuipers et al., 2023[65]). An exception is the non-drivers, a small group of respondents (Q8: 5.1%; Q9: 7.5%) with relatively low education levels, who had often not yet participated in a practical driving test, i.e., variable C4 equalled 0 (Q8: 65.9%, Q9: 57.5%). The negative relationship between the amount of driving and education level offers a possible explanation for the fact that people who drive more have a lower pass rate for the official car theory test and a lower mean score on the retention test. For example, respondents who drove more than 30,000 km per year (Q8) scored relatively poorly on the retention test (15.43 out of 20), did not pass as often on the first attempt (51.5%), were relatively less highly educated (41.7%), and typically male (68.2%) compared to those who drove less than 1,000 km per year (15.75 out of 20 on the retention test, 56.6% passed on the first attempt, 72.6% were highly educated, and 33.5% were male).

Gender differences (Q10) were very small in the official car theory test, with 55.3% of males (95% CI: 54.6–56.0) vs. 54.9% of females (95% CI: 54.3–55.4) passing on the first attempt. On the retention test, however, males scored slightly better (Mean: 15.79, 95% CI: 15.76–15.81) than females (Mean: 15.47, 95% CI: 15.45–15.50).

Regarding the 12 different provinces in the Netherlands, the mean score on the retention test ranged from 15.28 for North-Holland (a province in the west of the Netherlands) to 15.79 for Gelderland (a province in the east of the country). The pass rate on the first attempt of the official car theory test also varied from 48.2% for Zeeland (a southwestern province with relatively few respondents) to 57.5% for Gelderland. It appears that education level may explain differences between provinces, although the relationships involved could be complex. More specifically, provinces with a higher percentage of highly educated respondents (Q11), typically containing university cities, tend to show higher percentages of respondents passing the official car theory test on their first attempt (C2: $r = 0.64$, $p = 0.025$; note that Drenthe, Flevoland, Friesland, and Zeeland do not host a university). However, these same provinces also have respondents with lower mean mileage categories (Q8: $r = -0.94$, $p < 0.001$), i.e., respondents from highly educated provinces perform better on the official car theory test but drive less. Additionally, higher education correlates negatively with the percentage of women (Q10: $r = -0.56$, $p = 0.058$), and positively with the mean number of quarters between the official car theory test and the retention test (C3: $r = 0.65$, $p = 0.021$). Correlations with mean retention test scores ($r = 0.03$, $p = 0.921$) and mean age (C1: $r = 0.048$, $p = 0.110$) were weaker. These correlations are based on provincial averages ($n = 12$ provinces).

Table 2 shows that engaging in self-study (Q1), and particularly more hours of self-study (Q2), are associated with a *lower* likelihood of passing the official car theory test on the first try compared to taking a course or doing less self-study. This does not mean that self-study has a negative effect. It is likely that after failing, people engage in further self-study in order to pass. To better understand this pattern, we present individual characteristics based on the number of times a person participated in the official car theory test.

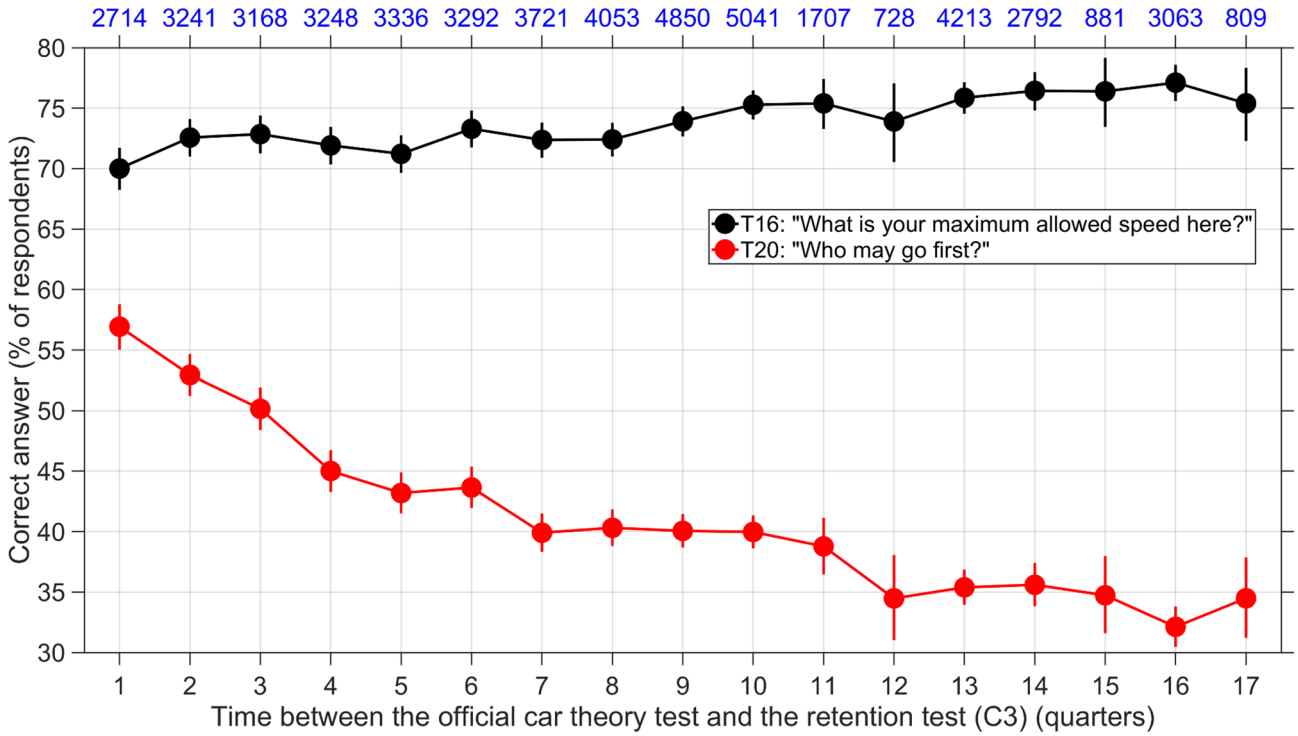


Fig. 3. Mean score on two selected items from the retention test versus the time in quarters between successfully passing the official car theory test and the retention test (C3). Also shown are corresponding sample sizes (blue numbers on top) and 95% confidence intervals calculated based on a binomial distribution (vertical lines surrounding each marker). See appendix Fig. C1 for the mean score per quarter on the 7 subjects.

Table 3 also shows that the percentage of respondents who engaged in self-study or took a course is related to the number of official car theory test attempts. There are different effects at play: First, people who needed fewer attempts were generally more highly educated individuals, who preferred self-study over a course with a live instructor (e.g., among those who passed on the first try, 65.4% of highly educated individuals used self-study only, compared to 39.9% for lower-educated individuals). Second, if people failed the official car theory test and thus needed another attempt, they may have chosen to take a course (Q1; course) to increase their chance of passing, or decided to engage in (additional) self-study (Q1; self-study). It should be noted that the people who needed multiple attempts are, by definition, those who have previously failed and thus may be experiencing difficulties with mastering the theoretical material (for a similar observation about attempts to pass medical examinations, see[46]).

Regression analysis

As can be seen in Tables 2 and 3, the independent variables collectively correlate with scores on the official car theory tests. To gain better insight into the predictive value of the different predictor variables for the score on the retention test, we performed a linear regression analysis. We only included predictors that we deemed theoretically meaningful and were available for all respondents. For example, we did not include the self-study duration (Q2) because these results were only available for those respondents who had undertaken self-study.

What is relevant to consider is the difference between the simple correlation between the predictor and criterion (r) and the standardised regression coefficient β. The results in Table 4 show that education level was the strongest predictor, a prediction that largely held in the regression analysis (r = 0.175 vs. β = 0.163). The effect of gender (r = −0.075 vs. β = −0.073) and age (r = −0.079 vs. β = −0.063) also proved robust.

The association with mileage, however, was reversed. While it initially seemed that mileage had a negative effect on performance in the retention test (r = −0.045, see also Table 2), after controlling for education level and the other predictors, the effect of mileage turned out to be slightly positive (β = 0.025).

Similarly, although Table 2 suggested that taking a course had a negative effect on retention (r = −0.108), the effect nearly disappeared in the regression analysis (β = −0.024). The positive effect of self-study also to a large extent diminished after controlling for the other variables (r = 0.131 vs. β = 0.087).

Finally, it can be seen that a longer duration between passing the official car theory test and the retention test was associated with a lower performance on the retention test, i.e., some degree of forgetting occurred. This effect was robust (r = −0.114 vs. β = −0.125). This negative trend is illustrated in Fig. 2.

Variable	Response options	*n* (%)	Mean score retention test (0–20) (95% CI)	Passed official car theory test on first try (%) (C2)	Higher education level (%) (Q11)
Type of preparation (Q1) *(multiple answers possible)*	Self-study	38,256 (75.2%)	15.75 (15.73, 15.78)	53.3	69.8
	Half-day course with live instructor	7,968 (15.7%)	15.35 (15.31, 15.40)	57.4	56.9
	Full-day course with live instructor	9,626 (18.9%)	15.20 (15.16, 15.25)	52.9	47.6
	Multi-day course with live instructor	3,134 (6.2%)	15.56 (15.49, 15.64)	53.8	52.8
	No preparation	561 (1.1%)	14.86 (14.65, 15.06)	48.8	36.2
	Other, namely	856 (1.7%)	15.52 (15.36, 15.67)	49.4	55.3
	I don't know	148 (0.3%)	14.68 (14.24, 15.12)	38.5	27.2
	Course with live instructor (derived variable)	20,376 (40.1%)	15.32 (15.29, 15.35)	55.3	52.3
	Self-study, without course with live instructor (derived variable)	29,416 (57.8%)	15.80 (15.78, 15.83)	55.1	73.2
	Course with live instructor, without self-study (derived variable)	11,536 (22.7%)	15.11 (15.08, 15.15)	61.6	47.6
Self-study duration (Q2)	0–24 h	7,009 (18.4%)	15.84 (15.80, 15.89)	59.6	78.2
	1–3 days	7,465 (19.6%)	15.71 (15.66, 15.76)	55.6	74.0
	4–7 days	8,365 (21.9%)	15.75 (15.71, 15.80)	53.6	72.8
	1–3 weeks	8,543 (22.4%)	15.82 (15.78, 15.87)	54.0	68.9
	3 weeks or more	6,788 (17.8%)	15.62 (15.56, 15.67)	43.7	51.8
Self-study intensity (Q3)	Less than 15 min	1,133 (3.6%)	15.61 (15.49, 15.72)	52.3	63.3
	15–30 min	7,954 (25.5%)	15.76 (15.71, 15.80)	54.3	67.2
	30 min to an hour	12,133 (38.9%)	15.73 (15.70, 15.77)	50.9	67.6
	One to two hours	7,574 (24.3%)	15.70 (15.65, 15.75)	50.0	67.3
	More than two hours	2,367 (7.6%)	15.81 (15.73, 15.90)	56.7	71.3
Preparation location (Q4) *(multiple answers possible)*	At home	38,619 (95.6%)	15.76 (15.74, 15.78)	53.5	69.5
	At the theory test provider	6,702 (16.6%)	15.46 (15.41, 15.51)	48.1	53.8
	Outside the home in a quiet place	2,846 (7.0%)	15.97 (15.90, 16.04)	51.0	73.7
	At another location	1,852 (4.6%)	15.78 (15.68, 15.88)	50.2	64.8
Main preparation location (Q5)	At home	6,229 (69.5%)	15.75 (15.69, 15.80)	46.3	63.0
	At the theory test provider	2,004 (22.4%)	15.56 (15.47, 15.65)	55.2	59.7
	Outside the home in a quiet place	347 (3.9%)	15.80 (15.59, 16.02)	56.5	70.2
	At another location	384 (4.3%)	15.90 (15.70, 16.10)	58.3	73.1
Used training resources (Q6) *(multiple answers possible)*	Theory (e-)book	31,424 (62.5%)	15.75 (15.73, 15.77)	52.7	71.0
	Practice tests	38,288 (76.1%)	15.71 (15.69, 15.73)	54.3	68.5
	Video lessons	17,673 (35.1%)	15.65 (15.61, 15.68)	49.9	60.2
	Online portal	18,700 (37.2%)	15.65 (15.62, 15.68)	52.1	63.0
	Other, namely	1,647 (3.3%)	15.52 (15.42, 15.63)	56.8	57.5
	No resources	2,541 (5.1%)	14.99 (14.91, 15.08)	73.9	49.5
Time between preparation completion and retention test (Q7)	0–24 h	36,135 (71.1%)	15.62 (15.60, 15.64)	57.3	66.5
	24–48 h	8,652 (17.0%)	15.59 (15.54, 15.63)	52.3	61.1
	48 h or more	6,070 (11.9%)	15.45 (15.39, 15.51)	45.7	53.9
Mileage past 12 months (Q8)	I have not driven myself	2,576 (5.1%)	15.55 (15.46, 15.64)	49.8	51.9
	Less than 1,000 km/year	11,106 (21.8%)	15.75 (15.71, 15.79)	56.6	72.6
	1,000–2,500 km/year	8,828 (17.4%)	15.70 (15.66, 15.75)	58.9	72.5
	2,500–5,000 km/year	6,542 (12.9%)	15.57 (15.52, 15.62)	57.0	69.1
	5,000–7,500 km/year	4,501 (8.9%)	15.45 (15.38, 15.51)	54.0	62.9
	7,500–10,000 km/year	3,743 (7.4%)	15.48 (15.41, 15.54)	53.1	59.0
	10,000–15,000 km/year	4,077 (8.0%)	15.48 (15.42, 15.54)	54.8	57.1
	15,000–20,000 km/year	2,469 (4.9%)	15.41 (15.32, 15.49)	53.6	53.7
	20,000–30,000 km/year	1,921 (3.8%)	15.53 (15.43, 15.62)	51.3	49.6
	More than 30,000 km/year	1,766 (3.5%)	15.43 (15.33, 15.53)	51.5	41.7
	I really don't know	3,328 (6.5%)	15.56 (15.48, 15.63)	48.4	55.6

Continued

Variable	Response options	*n* (%)	Mean score retention test (0–20) (95% CI)	Passed official car theory test on first try (%) (C2)	Higher education level (%) (Q11)
Car usage past 12 months (Q9)	Never	3,833 (7.5%)	15.49 (15.41, 15.56)	47.9	53.3
	Less than once a month	2,413 (4.7%)	15.57 (15.49, 15.65)	56.6	84.0
	Once a month	6,695 (13.2%)	15.77 (15.72, 15.82)	59.8	83.1
	1–3 days per week	18,670 (36.7%)	15.82 (15.79, 15.85)	58.9	73.6
	4–6 days per week	9,627 (18.9%)	15.54 (15.50, 15.58)	54.6	58.9
	Every day	9,619 (18.9%)	15.13 (15.08, 15.17)	47.1	36.3
Gender (Q10)	Male	19,968 (39.3%)	15.79 (15.76, 15.81)	55.3	64.0
	Female	30,632 (60.2%)	15.47 (15.45, 15.50)	54.9	64.1
	X (gender neutral)	257 (0.5%)	14.91 (14.53, 15.28)	50.2	62.6
Level of education (Q11)	Lower	18,035 (35.5%)	15.10 (15.07, 15.13)	44.8	0.0
	Higher	32,160 (63.2%)	15.88 (15.86, 15.90)	61.2	100.0
	Don't know/prefer not to say	662 (1.3%)	14.88 (14.69, 15.08)	36.1	—
Province (Q12)	Drenthe	1,362 (2.7%)	15.79 (15.68, 15.90)	53.3	54.4
	Flevoland	1,258 (2.5%)	15.47 (15.35, 15.59)	49.4	57.2
	Friesland	2,030 (4.0%)	15.67 (15.58, 15.76)	56.6	57.4
	Gelderland	7,040 (13.8%)	15.79 (15.74, 15.84)	57.5	64.6
	Groningen	2,319 (4.6%)	15.79 (15.70, 15.87)	56.1	69.2
	Limburg	2,701 (5.3%)	15.55 (15.47, 15.63)	54.7	59.7
	North-Brabant	6,975 (13.7%)	15.64 (15.59, 15.69)	56.1	61.4
	North-Holland	7,321 (14.4%)	15.28 (15.23, 15.33)	53.1	67.0
	Overijssel	4,066 (8.0%)	15.82 (15.75, 15.88)	55.0	62.1
	Utrecht	4,447 (8.7%)	15.64 (15.58, 15.70)	57.9	72.6
	Zeeland	1,083 (2.1%)	15.49 (15.36, 15.61)	48.2	52.7
	South-Holland	10,255 (20.2%)	15.49 (15.45, 15.53)	53.9	65.0
Questionnaire location (Q13)	At home	35,384 (69.6%)	15.62 (15.60, 15.64)	54.7	63.6
	On the go	3,866 (7.6%)	15.50 (15.43, 15.57)	56.4	71.5
	At my workplace	6,438 (12.7%)	15.49 (15.44, 15.54)	54.0	58.1
	In another quiet place	2,550 (5.0%)	15.67 (15.59, 15.75)	58.6	71.3
	In another busy place	2,619 (5.1%)	15.54 (15.46, 15.62)	56.0	67.0

Table 2. Sample size per response option with corresponding mean retention test scores (including 95% confidence intervals [CIs]), percentage of respondents passing the official car theory test on their first attempt (C2), and percentage of respondents with a higher education level (Q11) (n = 50,857).

Number of official car theory tests to pass	Self-study (Q1) (%) ('only self-study' in parentheses)	Course with live instructor (Q1) (%) ('only course with live instructor' in parentheses)	Mean self-study duration (Q2) (1–5)	Mean no. of practical tests (C4)	Mean age (C1) (years)	Higher education level (Q11) (%)	Mean score retention test (0–20)
1 (*n* = 27,983)	72.8 (58.0)	40.3 (25.4)	2.904	1.293	22.43	70.9	15.7
2 (*n* = 10,429)	79.8 (64.5)	33.6 (18.3)	2.947	1.508	23.32	64.0	15.5
3 (*n* = 5,643)	79.1 (56.6)	41.1 (18.6)	3.134	1.578	23.89	57.4	15.4
4 (*n* = 2,966)	76.1 (49.0)	47.9 (20.8)	3.303	1.708	24.28	48.7	15.4
5 (*n* = 1,548)	73.2 (47.0)	49.5 (23.4)	3.432	1.806	25.23	42.9	15.3
6 (*n* = 850)	76.4 (50.0)	47.8 (21.4)	3.573	1.868	26.48	36.0	15.3
7 (*n* = 468)	73.3 (44.7)	52.1 (23.5)	3.811	1.919	27.13	31.0	15.0
8 (*n* = 310)	72.3 (44.2)	49.7 (21.6)	3.702	2.081	27.99	24.0	15.0
9 (*n* = 208)	69.7 (46.2)	47.6 (24.0)	3.897	2.216	28.77	24.1	14.7
10+ (*n* = 452)	74.1 (52.0)	41.8 (19.7)	3.928	2.659	31.72	23.0	14.7

Table 3. Individual characteristics and preparation methods as a function of the number of official car theory tests completed.

Predictor variable	Percentage	Mean	SD	*r*	β (95% CI)
Self-study (Q1)	75.5	–	–	0.131	0.087 (0.075, 0.098)
Course with live instructor (Q1)	39.9	–	–	−0.108	−0.024 (−0.035, −0.013)
Gender (Q10) (female)	59.7	–	–	−0.075	−0.073 (−0.082, −0.064)
Age (C1) (years)		23.14	6.33	−0.079	−0.063 (−0.072, −0.054)
Education level (Q11) (higher)	64.7	–	–	0.175	0.163 (0.154, 0.172)
Yearly mileage category (Q8) (1 to 10)		4.32	2.41	−0.045	0.025 (0.015, 0.035)
Time between official car theory test and retention test (C3) (quarters)		8.35	4.38	−0.114	−0.125 (−0.134, −0.115)

Table 4. Percentage of respondents (in case of binary variables) or means and standard deviations (SD) (in case of non-binary variables), as well as zero-order correlation coefficients with the score on the retention test (r), standardised regression coefficients for predicting the score on the retention test (β), and their 95% confidence intervals (CI). *Note.* $p < 0.001$ for all reported *r* and β values. Overall prediction accuracy of the linear regression model: $r = 0.26$. Car usage (Q9) was not included in the regression model because it was highly correlated with mileage (Q8), $r = 0.63$. The correlation coefficients and regression analysis were based on 46,779 respondents; respondents with gender X, no information on education level, or no mileage category ("*I do not know*" responses) were not included. Predictor variables were weakly correlated with each other, $|r| < 0.20$, except for self-study and education level ($r = 0.21$), course and education level ($r = -0.20$), self-study and course ($r = -0.61$), and yearly mileage category and number of quarters ($r = 0.37$).

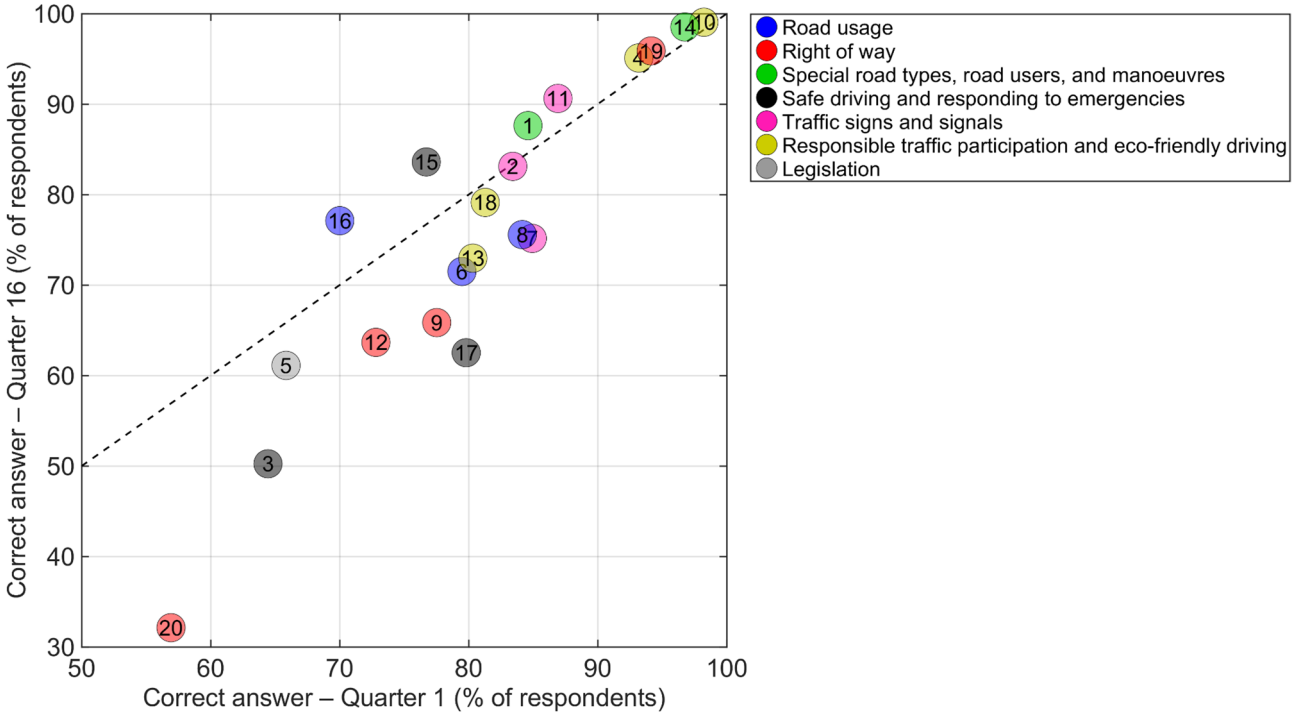


Fig. 4. Percentage of correct answers for 20 individual retention-test items, comparing respondents who passed the official car theory test 3 to 5 months ago (Quarter 1; $n = 2{,}714$, horizontal axis) with those who passed 48 to 50 months ago (Quarter 16; $n = 3{,}063$, vertical axis), based on variable C3. Markers below the diagonal dashed line indicate a decrease in correct responses over time (possible forgetting), while markers above the line indicate improved scores. Each of the seven subject categories (Table 1) is represented by distinct marker colours. Independent-samples *t*-tests showed significant differences ($p < 0.05$) between Quarters 1 and 16 for all items, except for Item 2.

Item-specific effects

During an exploration of the scores of the 20 individual items from the retention test, we discovered that some items were more susceptible to forgetting than others. An example of this is illustrated in Fig. 3. For Item 20, the score was initially low and substantially decreased (and from Quarter 3 onward, even below the guessing rate) the longer it had been since the respondent passed the official car theory test. Item 16 is an example of an item where the score actually improved as more time passed. Figure 4 shows that a large portion of items are

characterised by a lack of retention, i.e., the marker is (substantially) below the diagonal dashed line, but that performance on some items *improves* over time (i.e., marker is above the diagonal dashed line). The full 20-item correlation matrix of the retention test can be found in appendix B (Fig. B1).

The differences in retention trends between items, meaning whether respondents perform better or worse over the years, seem to be partially explained by the content of the item. Item 16 is an example of an item on which one could plausibly perform well due to accumulated driving experience. This type of traffic sign (see Table 1) may still appear somewhat unfamiliar to someone with little driving experience, but the sign is frequently encountered on Dutch roads. Item 20, on the other hand, can be seen as an item where driving experience may dictate that the pedestrian has the right of way. However, the correct answer is, counterintuitively, that the car has the right of way, despite the stop line and stop sign (see Table 1).

Discussion

Study characteristics

Over 50,000 respondents completed a questionnaire including a retake theory test for obtaining a car driver's licence in the Netherlands. This retention test consisted of 20 questions for the sake of time, compared to the usual 40 questions. The retention test did not include a hazard perception test, an aspect that is part of the official car theory test in some countries (e.g., Netherlands[42]. UK[47]), and which has separate theoretical foundations[48,49], and validation studies[50–52]. However, our retention test did meet the characteristics of the knowledge questions of an official car theory test. The aim of our study was to investigate the predictors of knowledge retention, i.e., a high score on the retention test.

Before discussing the results, several limitations must be considered. First, the response rate to the questionnaire was only 5.8%. Prior research has shown that novice drivers often do not respond to questionnaires (see[53], with a response rate of 13%). One explanation is that the invitations were sent to a large number of people, namely all Dutch individuals who obtained their theory certificate. Previous research indicates that large-scale studies tend to yield low response rates, possibly because they are perceived as less personal or relevant[54]. Another reason for our low response rate could be that some email addresses were outdated. Furthermore, we decided not to send reminder invitations to keep the study minimally invasive for people's inboxes. In comparison, a questionnaire study on the topic of learning to drive in the UK [8; 128,000 invited drivers] and accompanied driving in the Netherlands[55], 97,079 invited drivers] showed response rates of 33% and 32%, respectively. Differences were that these questionnaires were sent by regular mail, and a reminder letter was sent as well.

It is important to contextualise our study's four-year retention period within the broader literature on memory retention and forgetting. While we characterize our study as examining "long-term" memory retention, we acknowledge that our four-year timeframe could be considered medium-term relative to durations commonly investigated in the broader retention literature. Laboratory studies of memory typically examine retention over periods ranging from seconds to weeks[56,57], with anything beyond working memory (i.e., 10–30 s) considered "long-term" in cognitive psychology[58,59]. In contrast, studies of "very long-term memory" have examined retention periods from 1 to 15 years[60,61] and even up to 30–50 years[39,62]. Our four-year timeframe falls between these laboratory and very long-term studies, providing insights into a period where both forgetting and reinforcement through practice are likely occurring simultaneously.

As for the current sample, the overall pass rate for the official car theory test, based on the number of attempts people needed to pass, was 48.3% (with a first-time pass rate of 55.0%). This pass rate is higher than the national average (40.7, 43.0, 38.1, 36.0, & 38.6% for 2019–2023; based on annual reports[63]). One explanation for this discrepancy is that people who never passed their official car theory test were not invited for the current questionnaire, and that persons with better theory knowledge may generally be more inclined to participate.

Our sample consisted mainly of women (60.5%; respondents with gender neutral identification were excluded from this calculation), whereas a more equal gender distribution would be expected nationally. In comparison, in the Netherlands in the age category 20–25, 71.4% of males and 69.6% of females have a driver's licence[64]. An overrepresentation of women in questionnaire studies among novice drivers has been found before[8,55,65]. We found no gender difference in pass rates on the official car theory test, which is consistent with earlier research from the Netherlands[3], but see findings from the UK and Sweden showing that females achieved higher pass rates on car theory tests compared to males[4,66]. In the retention test, males slightly outperformed females. It is possible that this gender difference arose from self-selection (e.g. perhaps more capable people decided to participate in our study) or due to item-sampling effects. For example, males performed better than females on a question about the weight of a delivery van (T5) (males: 66.9% correct; females: 58.3% correct). Conversely, females outperformed males on a number of questions, such as one on fog lamps (T3) (males: 52.8%; females: 58.1%) and safe actions in an emergency (T15) (males: 77.7%; females: 82.4%).

A key strength of our study is its large sample size, which enabled even small effects to attain statistical significance. The observed effect sizes were generally moderate, which is expected given that scores from a brief 20-question test typically have limited reliability. In our study, the internal consistency of the retention test (Cronbach's alpha), calculated from a matrix of 50,857 participants answering 20 questions (coded as 0 = incorrect, 1 = correct), was relatively low at 0.335. Furthermore, retention test scores likely depend on additional factors not captured by our questionnaire. Despite these limitations, our linear regression model, which included only a small number of predictors, yielded a moderately accurate prediction of retention test scores (correlation coefficient $r = 0.257$). Correcting this correlation for measurement error in the outcome by dividing by the square root of Cronbach's alpha results in a partially disattenuated correlation of 0.444.

Main results

As hypothesized, the type of preparation and time elapsed have significant effects on the knowledge retention of the official car theory test. However, in discussing the main results, it is important to note the large role of

self-selection. For example, respondents who engaged more extensively in self-study (variable Q2) had a *lower* likelihood of passing the official car theory test on their first attempt. This does not mean that studying has a negative effect on knowledge acquisition. A likely explanation for this association is that initially failing the test means that more study is required to eventually pass, or that people who struggle with learning need more time to understand the material in order to succeed. Due to these self-selection effects, it is difficult to make causal inferences about the influence of preparation methods on the likelihood of passing the official car test and performance on the retention test, which took place up to four years later.

When only the mean scores are considered (see Table 2), it appears that solely taking a course with a live instructor results in lower retention, with a mean of 15.1 out of 20 on the retention test, compared to people who only did self-study, with a mean of 15.8 out of 20. However, this difference can largely be explained by the self-selection of the preparation method, particularly in relation to education level. In the linear regression analysis, the effect of the preparation method (self-study or course) was substantially weakened compared to the zero-order correlations (see Table 4). This means that the effect of the preparation method is not standalone, but is partly explained by additional variables such as education level (i.e., people with a higher level of education more often choose self-study) and mileage (i.e., people with a lower education level drive more kilometres per year). Given the lack of robustness of the variables, and the risk of *omitted variable bias* (i.e., there may be other variables, such as self-efficacy, intelligence, or type of profession, that could provide further explanation but were not inquired about in the questionnaire), we cannot make causal statements about the effect of the preparation method on the retention test score. Future research would benefit substantially from more advanced methods of causal inference[67], to explicitly examine interactions between measured and omitted variables, such as how cognitive ability[68] shapes the choice of learning strategies and affects long-term retention.

Although it is not possible to make definitive statements about whether the type of preparation for the official car theory test has a detectable effect on the current retention test, we can assert that other phenomena influence retention. In particular, we identified item-specific effects where performance on some items remained stable or even improved over the years. Furthermore, given the positive correlation between yearly mileage and how many quarters had passed since passing the official car theory test ($r = 0.37$), these performance improvements suggest that accumulated driving experience may be the cause of improved performance on the retention test. This corresponds with literature indicating that activation of knowledge and meaningful integration of knowledge can counteract forgetting[69–71].

For about half of the items of the retention test, performance declined over time; in other words, these items were susceptible to forgetting. This was especially true for items that were already difficult from the start, perhaps because the knowledge had already started to fade in those months after passing the official car theory test. Forgetting seemed to apply to items that seemed more rule-based, including items T20 (right-of-way rule), T3 (rule regarding which lighting is permitted), T12 (right-of-way rule), and T17 (rule concerning the height of a child in a car seat). This observation is supported by statistical analysis (Principal Component Analysis; PCA), as presented in appendix D. From this PCA, we retained two orthogonal components, which we labelled as: (1) "static rules and regulations", and (2) "dynamic/operational and safety". The correlational analysis (see Fig. B1) shows that scores on the first component decrease over time since the official theory test ($r = -0.17$), whereas scores on the second component increase ($r = 0.08$). These results are consistent with literature on procedural versus declarative knowledge[33], and with the fact that behaviours become automated through practice and experience [34]. Our results also indicate that retention of theoretical knowledge is item-specific, which potentially offers an important perspective for test developers worldwide.

Finally, despite the role of self-selection, it remains possible to draw cautious conclusions about causality from these results. Specifically, respondents who took a course with a live instructor, without engaging in additional self-study, achieved a higher first-time pass rate on the official test (61.6%) compared to respondents who relied exclusively on self-study (55.1%). This finding is particularly noteworthy because individuals opting for self-study were predominantly those with higher educational backgrounds, a group exhibiting higher first-time pass rates (61.2%) than respondents with lower educational attainment (44.8%). Thus, the observed advantage of instructor-led courses is unlikely to be driven by educational differences, which supports the inference of a causal relationship.

Conclusions and recommendations

Through a study with 50,857 respondents, this research investigated how preparation methods, time elapsed since the official car theory test, and demographics were related to performance on the official car theory test and to knowledge retention, as reflected by the score on the retention test over time. The questionnaire was administered up to four years after the respondent had passed the official car theory test. The current study is unique in its kind in investigating factors that influence the retention of knowledge of theory test candidates.

From the results, the following conclusions can be drawn:

- There are substantial self-selection effects, with higher-educated individuals mainly opting for self-study, and lower-educated individuals tending to take a course with a live human instructor.
- No statements can be made regarding a causal effect of the preparation method on the retention test score. Education level and driving experience are relatively strongly associated with the score on the retention test and substantially attenuate the effects of the preparation method. Therefore, it seems that it is not the preparation method per se, but rather other factors such as education level, that explain the score on the retention test.
- Taking a course with a live instructor seems to be effective for passing the official car theory test.
- Elapsed time (or the driving experience gained during that time) has a negative relationship with retention test performance, with the total score on the retention test decreasing the longer it has been since one passed (and prepared for) the official car theory test.

- Some items on the retention test are susceptible to forgetting, while for other items, retention test performance improves over time. An explanation has been found in terms of the degree to which driving experience provides functional anchoring of the knowledge or rule. Priority rules and other rules that are somewhat isolated or counterintuitive tend to be forgotten over time.
- Methodologically, large-scale investigations of long-term knowledge retention face significant challenges in controlling for all relevant variables. Despite our substantial sample size ($n > 50{,}000$) and several significant findings, establishing causal relationships remained problematic. Future research in this domain should implement robust research designs that account for potential confounding variables and employ advanced statistical techniques to mitigate omitted variable bias.

The following recommendations can be formulated, for theory-test takers on the one hand, and theory-test organisations and legislators, on the other:

Recommendations for theory-test takers

For theory-test takers, the goal is likely straightforward: to pass the test. The current results offer guidance on how to achieve this goal, in that taking a course with a live instructor is associated with an increased likelihood of passing the official car theory test. Specifically, the current research suggests (but does not prove) that courses led by a live instructor increase the likelihood of passing the official car theory test on the first attempt, without clear evidence of reduced knowledge retention. This latter observation is supported by the regression analysis outcome which showed a negative but near-zero effect of a course with a live instructor.

There is a group of candidates, often with lower educational backgrounds, who repeatedly attempt the official car theory test by relying solely on self-study. For them in particular, a course could offer an alternative. The advantage of a course may lie in that it structures the learning process through examples and guidelines, which may support efficient learning. Studies have shown that offering examples[72,73], or encouraging learners to generate their own examples[74] can help them move beyond simply memorising declarative concepts.

Recommendations for theory test organisations and legislators

Compared to test-takers, testing organisations have a broader range of objectives. They aim for tests to be fair, reliable, and valid, in the sense that test-takers retain and maintain the safety-relevant knowledge throughout their driving careers.

Considering these objectives, testing organisations such as the CBR may wish to assess the desirability of courses with live instructors. While these courses overall appear to positively impact the pass rate, it is important to ensure they contribute to a genuine understanding of traffic theory rather than focussing solely on test preparation. Although our research does not suggest that courses negatively impact knowledge retention, it is worth considering whether or how these courses effectively support a thorough understanding of traffic theory.

At the same time, restricting courses may be inadvisable, as our evidence suggests that passing the official car theory test is challenging for some groups of primarily lower-educated individuals (see Table 3). Testing organisations may wish to consider a 'middle ground' by providing clear practice questions and guidelines for self-study candidates. Such an approach could prevent students from unnecessarily struggling with understanding what is expected of them and what constitutes an effective learning strategy.

Finally, the content of the official car theory test may require re-evaluation. Based on our findings regarding knowledge decay (see e.g., Fig. 3), the testing organisations could initiate discussions with government agencies to address test items, or the validity of particular traffic rules, that may be of limited practical relevance. Examples are the item about right of way where a car counterintuitively has priority over a vulnerable road user (Item 20), or an item regarding the maximum permitted height for children in car seats (Item 17). Related to this, it should be considered to what extent certain traffic rules, or questions about these rules, are unnecessarily 'intellectual'. For example, in an explorative analysis (see Fig. B1), we found that the correlation (phi coefficient) between education level (binary variable) and providing a correct answer to the question (also a binary variable) was strongest for Item 2 (phi = 0.14), concerning a relatively rare and innovative traffic sign in the Netherlands describing the 'taper solution' (a lane that ceases to exist). It can be questioned whether such concepts, although undoubtedly effective from an engineering standpoint, are too demanding for some drivers to understand or remember. In certain cases, cognitive offloading strategies, such as labelling the maximum permitted height on the child seat itself, might be more effective than requiring drivers to memorise such details. Conversely, it could be sufficient for prospective drivers to simply know that such rules exist, without needing to memorise the specifics; for example, the allowed height of the child in the child seat can be looked up when needed. This viewpoint corresponds with the concept of "consequential validity", where the test encourages people to learn and reflect on the material (see[75], regarding the practical driving exam).

Data availability

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Received: 12 December 2024; Accepted: 29 May 2025
Published online: 01 July 2025

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Acknowledgements

We would like to thank I&O Research for their assistance in crafting and distributing the questionnaire. Additionally, we are grateful to the Theory Division of the CBR, LENS Verkeersleermiddelen, Smit Rijschoolservice, and Verjo B.V. for their support in developing the retention test. Joost de Winter is supported and works on the Transitions and Behaviour project ("Towards Safe Mobility for All: A Data-Driven Approach"; 403.19.243), provided by the Dutch Research Council (NWO).

Author contributions

D.S. and J.W. wrote the main manuscript and performed the analyses for the results, D.H. wrote parts of the

main manuscript, coordinated the execution of the initial project (D.S. assisted in this), and assisted in the further analyses and writing of the manuscript, and S.H. facilitated the project, the analyses, and completion of the manuscript. All authors reviewed and provided feedback on the manuscript. D.S., D.H., and J.W. addressed the comments of the reviewers and amended the manuscript accordingly, while S.H. provided a general check on the revised manuscript as well.

Declarations

Competing interests
The authors declare no competing interests.

Additional information
Supplementary Information The online version contains supplementary material available at https://doi.org/10.1038/s41598-025-04796-6.

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