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ORIGINAL PAPER

Effectiveness of two cognitive training programs on the performance of older drivers with a cognitive self-assessment bias

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Abstract

Purpose Depending on the calibration of their cognitive abilities, some older drivers (ODs) might stop driving prematurely (under-estimators, UEs) and others could expose themselves to risky situations (over-estimators, OEs). The aim of the study was to compare the effectiveness of two cognitive training (CT) programs intended for ODs presenting a cognitive calibration bias. We hypothesized that CT with feedback on performance can help ODs to correctly calibrate their abilities and consequently adapt their driving behavior.

Method One hundred and six ODs (≥70 years) were assigned to two CT groups (with or without a driving simulator experience, DS). These interventions lasted about 36 h and were distributed over a 3-month period. ODs completed objective and subjective cognitive evaluations and an on-road driving evaluation before and after training.

Results The first results on 67 participants (40 from the CT group, and 27 from the CT + DS group) showed an improvement of their visual processing speed, their divided attention and their selective attention after training. Participants from both groups also had an improved TRIP tactical sub-score (Test Ride for Investigating Practical fitness to drive), indicating a better driving behavioral adaptation. Finally, although both training programs seemed to be equally effective in correcting cognitive calibration bias, the results indicated that 21 UEs and 10 OEs were well calibrated and thus correctly self-assessed their cognitive abilities after training.

Conclusion Both CT programs (with or without DS experience) seem to improve the visual attention of ODs. UEs appeared to be more susceptible than OEs to this training and were better calibrated after it.

Keywords Cognitive training program · Driving simulator · Older driver · Self-assessment · Calibration

1 Introduction

Over the last half-century in industrialized countries the number of older adults has increased and one quarter of the population will be aged 65 or older by 2050 [1]. This population aging will be accompanied by an increase in the number of older drivers on the roads some of whom may present a risk of being involved in a traffic accident [2, 3]. Normal aging may affect driver safety as it entails a decrease in visual, psychomotor and cognitive abilities that are needed in driving [4]. Moreover, older drivers are physically more fragile and vulnerable than younger ones, and present a major risk of injury during a road accident [5].

Several traffic situations, such as night driving, driving during rush hour, in bad weather, on the highway or in an unfamiliar place, can be stressful or difficult for older drivers who, in order to deal with age-related cognitive decline, choose (or are obliged) to stop driving [6]. This driving cessation could have negative consequences, such as social isolation or increased risk of depression [7–10]. However, older

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drivers can adapt their driving behavior to the age-related functional and cognitive decline by avoiding these difficult driving situations [11–14], or by developing compensatory strategies (e.g. by increasing safety distances, reducing speed or reducing distances traveled) [13–19]. This behavioral adaptation reflects driving self-regulation, which allows the driver to continue driving safely despite age-related changes [20]. But not all older drivers self-regulate their driving behavior [11, 21–23]. For example, it has been shown that drivers with poor cognitive performances and drivers who are not aware of their own abilities are less likely to avoid difficult driving situations than those with higher performances or who are aware of their own abilities [22, 23]. A driver's behavior depends on his perception of his own abilities and on his capacity to drive safely, both of which are related to the driver's cognitive, sensorial and physical abilities [4]. To be engaged in the behavior change process and thus self-regulate his driving, the driver should be aware of his own abilities (insight), i.e., he has to be able to perceive changes in his driving ability [24]. This insight might be correct or not. The calibration is defined as the balance between perceived and actual abilities [25]. When the driver is correctly calibrated, his perceived abilities are in alignment with his actual abilities and his driving self-regulation is adapted to his abilities. Conversely, the driver presents a calibration bias when perceived and actual abilities are misaligned, which leads to incorrect driving self-regulation. Hence, improvement in both awareness of cognitive difficulties and cognitive performance seems important to help older drivers to self-regulate their driving behavior correctly.

Various interventions have been developed to help older drivers to self-regulate their driving behavior and thus maintain safe driving, such as self-assessment questionnaires and self-screening tools [26–31], educational interventions associated or not with practical driving training [32–41], and cognitive training programs [42–48]. Self-assessment questionnaires of cognitive, physical and sensory driving-related abilities and self-screening tools of driving-related difficulties have helped older drivers to i) become aware of age-related changes that could affect their driving, ii) initiate discussion with family on driving cessation, and iii) self-regulate their driving behavior [26–31]. However, further investigations should be conducted to find out whether these self-declared behavioral changes are actually implemented during real driving. Among the other interventions developed, educational interventions were performed with an occupational therapist who: i) reminds older drivers of driving rules, ii) gives recommendations for safer driving, and, iii) gives information about age-related driving difficulties [32–38]. Although these educational interventions have initiated changes in driving habits and behavior [32, 34, 35, 37], they had no effect on on-road driving performance [38], and were not associated with crash rate reduction [33, 36]. Furthermore, if they are not conducted by professionals accustomed to referring also to positive aging effects, this type of intervention could have an effect opposite to that expected and thus activate the stereotype threat in older adults [49]. This psychological concept reflects the confirmation of a negative stereotype of a group to which the person belongs [50]. This stereotype has a negative effect on driving-related cognitive performances [51] and driving performances [52] and hinders older drivers from correctly self-regulating their driving [53]. Educational interventions associated with practical driving training (performed on-road or with a driving simulator) improve older drivers' knowledge of traffic rules and road safety [39, 41], and also reveal transfer to on-road driving of skills acquired on a simulator (i.e. increased visual inspections in mirrors and blind spots before lane changing) [40]. Several studies have also investigated the benefits of cognitive training programs in terms of older drivers' driving performances. Even though cognitive training focused on speed of processing and visual attention improves these cognitive abilities relevant to driving safety [42, 43, 45, 48], contradictory results have been reported regarding the beneficial effects of cognitive training on simulated or on-road driving performance [42–44, 46, 47]. One study showed a reduction in dangerous maneuvers on the road [42] and another showed improved braking reaction time on a driving simulator [46]. However, other studies showed no improvement of driving performances after cognitive training [43, 44, 47]. Hence, the effectiveness of cognitive training programs needs to be confirmed in on-road studies. Discrepancies in the benefits of cognitive training in terms of on-road performance may be due to the different levels of self-awareness of older drivers. People who are aware of their own abilities may make better use of adapted strategies learnt during these programs, because self-regulation largely depends on drivers' abilities to evaluate their own driving and is influenced by drivers' abilities to have insight into their declining driving performance [25]. However, it is also necessary to understand whether people who are not conscious and aware of their own abilities could or could not take full advantage of the content of these programs. Our study is based on the hypothesis that older drivers' training needs depend on the drivers' self-assessment of their cognitive abilities, which also influences their driving behavior [4, 24, 25]. Kruger and Dunning (1999) showed that those who perform poorly in logical reasoning or grammar exercises vastly overestimate their abilities and have deficient metacognitive skills in comparison with their more skilled counterparts [54]. A correct self-assessment of cognitive abilities would lead well-calibrated people to adapt their behavior correctly, and consequently to self-regulate their driving activity correctly. Among the cognitive incorrect estimators, over-estimators (OEs) and under-estimators (UEs) can be described. OEs think that they have greater cognitive abilities than their same-aged peers, but they do not. UEs think that they have poorer cognitive abilities than their same-aged peers, but they do not. Thus, an intervention that aims to improve older drivers' self-awareness of their cognitive abilities could allow both OEs and UEs to calibrate themselves better. The aim is, for OEs, reduced risk of injury exposure, and, for UEs, improved self-confidence and continued driving.

The purpose of this study was to compare the effectiveness of two training programs: pure cognitive training and the same cognitive training coupled with three driving simulator training sessions, both programs being addressed to older drivers presenting a cognitive self-assessment bias. The effectiveness of both programs was evaluated in terms of changes in the calibration of older drivers' cognitive abilities and changes in their cognitive and driving performances. The first hypothesis was that cognitive training would allow drivers to calibrate their cognitive abilities better, thanks to feedback on performance received throughout training. As this training was focused on cognitive functions required while driving, the second hypothesis was that the driving simulator experience would allow the transfer of the training benefits to the road, by improving driving performance. This paper presents some preliminary results obtained with a subgroup of participants.

2 Method

2.1 Participants

Participants included in our study came from the Safe Move cohort, which comprised 1200 drivers over 70 years old. The calibration of their cognitive abilities was determined by comparing their objective and subjective cognitive performances. The objective cognitive performances were determined using the results from the Wechsler Digit Symbol Substitution Test (DSST) and the Trail Making Test (TMT) parts A and B. These objective data were compared with normative data (i.e. values for participants of the same age and same educational level as the participants in the present study). This comparison allowed classification of the participants according to their objective cognitive level as "high", "medium" or "low". The subjective cognitive performances were collected from a self-assessment questionnaire described below. These subjective data allowed classification of participants depending on the perception of their own cognitive abilities as: "better than the others", "like the others", or "worse than the others". By crossing the objective and subjective data, three profiles of drivers emerged: UEs (15 % of the cohort, or 180 drivers), correct estimators (CEs, 42 % of the cohort, or 502 drivers), and OEs (43 % of the cohort, or 508 drivers) [55]. One hundred and twenty drivers (OEs and UEs), recruited from the cohort, were expected to be included in our study. The inclusion criteria were: driving at least three thousand kilometers per year, owner of a computer connected to the Internet, not suffering from motion sickness or vertigo or Menière's disease, and visual acuity higher than 5/10th as measured using a Monoyer chart.

2.2 Experimental design

This study used a 2 × 2 mixed experimental design consisting of one between-subject variable, the "Group", with two modalities: "cognitive training" (CT) and "cognitive training coupled with the driving simulator experience" (CT + DS); and a repeated measure of the evaluation (the "Time" factor, with two modalities: "the baseline evaluation" and "the post-training evaluation", three months later). Two groups were constituted, comprising an anticipated 40 participants (20 OEs and 20 UEs) performing computerized cognitive training (36 h) and 40 participants (20 OEs and 20 UEs) performing the same cognitive training (35 h) plus a driving simulator experience (1 h).

2.2.1 Computerized cognitive training program

We collaborated with Scientific Brain Training, a company specialized in cognitive training, which developed a training program called Happyneuron®. The effectiveness of this training method was demonstrated with healthy seniors in a study that assessed performances after completion of 500 exercises [56]. Twenty exercises with 15 difficulty levels each from the Happyneuron® program were used in our study. These exercises were specifically focused on functions required for driving, such as: i) attention (with, for example, exercises in which the aim is to click on moving ladybugs as often as possible while ignoring distractions; or evaluating the speed of moving objects), ii) memory (with, for example, exercises involving memorization of itineraries through different countries; or location of monuments in different cities across the world), iii) executive functions, such as updating, flexibility, or planning (with, for example, exercises in which a tower of rings is rebuilt by making strategic moves), and iv) visuospatial abilities (with, for example, exercises aimed at guessing from which point of view pictures were taken). All participants had a personal account on-line on the web platform where they could log in and complete their daily activity and get information on their last performances and progression in the program.[1] After completing an exercise, participants received three pieces of feedback about their performance: the score obtained (in percent), the average reaction time, and a sentence that encouraged them to continue.

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[1] The progression rules for the cognitive training were made by a virtual coach, who chose, for each exercise, the difficulty level: if the exercise was successful (100 %), the participant passed to the next level, if the score was between 70 and 99 %, the participant remained at the same level, and if the score was below 70 % three times in a row, the participant went down to the lower level).

Participants were told to train three hours per week for twelve weeks. The number of hours participants performed their activity was recorded on the web platform. The experimenter checked this playtime weekly and could also call the participants by phone to motivate them or to help them solve any difficulties they may have encountered. Total playtime was used as a dependent variable to measure the attendance of the participants.

2.2.2 Driving simulator experience

The study was carried out in an instrumented full-cab fixed-base simulator (308 Peugeot). This simulator consisted of virtual reality-based visual and audio systems, a computer program for vehicle motion simulation, and a host computer system for simulating the driving environment. The road scene was projected in front, on five screens (220 × 165 cm and 1024 × 1280 pixels) which provided an approximate 270° horizontal and 40° vertical view of the virtual environment. Force feedback was provided through the steering wheel, and auditory feedback was delivered in the form of engine and outside noises. Driving performance parameters were captured at 60 Hz from the sensors from the equipment (brake, accelerator and steering wheel). The simulator was also equipped with a CAN-bus system to send/receive information to/from the car. Microphones allowed interaction between the driver and the experimenter (e.g. giving instructions to the participant at the beginning of the simulation).

Before the first driving session, participants drove in an urban scenario for 10 min to familiarize themselves with the car and the virtual reality environment. Three simulated driving sessions each lasting 20 min were completed at regular time intervals by each participant of the experimental CT + DS group. Five training scenarios were used during each driving simulator session: potential hazard detection (i.e. pedestrian crossing), intersection with traffic lights, car following, left turn, and overtaking on a highway. Three difficulty levels were available for each training situation and a progression rule was also defined.[2] Each participant began the simulated drive at the easiest level. Feedback was given to the participant after each driving situation through a screen placed inside the vehicle. If the score was less than 50/100, the feedback consisted of the presentation of educational goals the participant was expected to reach at the next level. Conversely, if the participant successfully completed the exercise, the feedback congratulated him/her and indicated the progression to a higher difficulty level. To avoid the test-retest effect, alternative learning situations were developed and used in the following session. The participant, therefore, could not be faced with the same situation twice.

2.3 Cognitive evaluation

Cognitive performance was objectively evaluated with two paper and pencil neuropsychological tests, the TMT [57] and the DSST [58]. The TMT assessed processing speed, executive function (i.e. mental flexibility), and visual scanning ability and involved two parts. In Part A, the participant had to connect numbers in ascending order (from 1 to 25) as fast as possible. In Part B, the participant had to connect numbers (from 1 to 13) and letters (from A to L) in ascending or alphabetic order and alternate a number and a letter (1-A-2-B-3-C, etc.) as fast as possible. The dependent variables were the time per transition and the number of correct transitions for each part, and the number of perseverations (when the participant failed to alternate numbers and letters) for Part B. The DSST assessed psychomotor processing speed. This test involved a grid with digits from 1 to 9 and their corresponding symbols, and below, a grid with only the digits. The participant had to fill the grid with the associated symbols, in 90 s, as fast as possible. The dependent variables were the number of correct symbols and the number of errors.

Cognitive performance was also evaluated subjectively, with a self-assessment questionnaire composed of four questions. Participants had to rate their own cognitive abilities on Likert scales, compared with same-aged peers. For example, a question about focused attention was “Compared with people of the same age, is it more or less difficult for you to concentrate?” The participant had to answer on a five-point scale ranging from “Much less difficult” to “Much more difficult”. A self-assessment score was calculated by adding the responses to the different questions.

Finally, the Useful Field Of View test (UFOV®) [59] was performed to assess the speed of processing and visual attention of our participants. This computerized test of visual attention took place on a computer provided with a 17″ screen. It included three subtests, assessing processing speed, divided attention, and selective attention.

2.4 Driving evaluation

The on-road driving evaluation was conducted by a driving instructor seated at the right of the driver, and by the experimenter seated behind the driver, in an instrumented vehicle. This car was a 5-speed manual transmission 307 Peugeot, fitted with dual controls and dual rear-view mirrors. The experimental vehicle was also equipped with video cameras to collect information about the driver’s behavior in real driving condition (front view: traffic and

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[2] Using an algorithm developed in our laboratory that assigns penalty points depending on the driver’s behavior, a performance score between 0 and 100 was calculated for each situation. When the score was equal to or less than 50/100, the participant remained at the same level and faced an equivalent situation during the next driving session. When the score was higher than 50/100, a higher difficulty level situation was unlocked and presented to the participant during the next driving session.

infrastructure, rear view: traffic, driver view: visual activity and verbalizations, driver and driving instructor view: overall driver behavior and actions of the instructor). Two different but equivalent road trips were performed at baseline and post-training in order to avoid the test-retest effect. During the first ten minutes, the participant drove to familiarize him/herself with the vehicle. The route combined: urban circuit, suburb and rural circuits and a section of ring road/highway. More precisely, the baseline evaluation trip took place in France in the cities of Bron, Chassieu and Villeurbanne, lasted about 40 min for 28 km, and was composed of an urban portion (13 km), a suburban/rural portion (5 km) and a highway portion (10 km). The post-training evaluation trip took place in the cities of Bron and Saint-Priest, also lasted 40 min and was 25 km long. It was composed of an urban portion (8 km), a suburban/rural portion (7 km), and a highway portion (10 km). These portions were similar in terms of duration, road types and infrastructures (intersections, roundabouts, insertions or ring-road exits, or lane changes). The driving instructor gave the directions to the driver throughout the trip.

Two grids were used to assess the driving performance; one always completed by the driving instructor and the other one always completed by the experimenter. The reliability of the scoring methods was assessed by the correlation between the TRIP total score and the penalty total score at both baseline and post-training evaluation. The driving instructor and the experimenter were blind regarding the cognitive profile of the participant (OE or UE).

2.4.1 Test ride for investigating practical fitness to drive (TRIP)

The first grid is an adapted French version of Test Ride for Investigating Practical fitness to drive (TRIP) [60, 61]. This grid assessed eleven dimensions of driving: vehicle position on the road, vehicle tracking, speed, visual behavior, road signs, overtaking, anticipatory reactions, communication with other road users, exposure to specific situations (such as left-turn or dual carriageway), vehicle handling, general impressions of the instructor. Each of these dimensions was evaluated as: insufficient, doubtful, sufficient, good or not applicable. The driving instructor completed this grid at the end of the course, which led to an overall score out of 100 points, and to three sub-scores: the tactical sub-score, out of 46 points, which takes into account speed and safety distance choices made by the driver; the tactical compensation sub-score, out of 20 points, which reflects the behavioral adaptation of the driver depending on the traffic situation and road design, and finally, the operational sub-score, out of 39 points, which considers vehicle handling and mechanical operations by the driver [61].

2.4.2 The behavioral observation grid

The second grid was completed in real time during the trip by the experimenter seated behind the driver. This pre-established observational grid consisted of a description of the situations encountered and a list of the potential driving behaviors, gathered into broader dimensions to simplify coding: visual attention, interaction with other road users, planning, lane positioning, speed adaptation, car control handling, and driving instructor interventions. This detailed list of situations and potential behaviors limited the subjectivity of coding [62, 63]. In addition, the experimenter could mention any unplanned event affecting the driver's behavior, or any action made by the instructor. The video recording allowed completion of the grid if the experimenter missed an event in real time. From this grid a total penalty score and seven penalty sub-scores (one for each dimension) were calculated, based on the driver's behavior.

2.5 Procedure

The first time the participants came to the laboratory, the study was presented to them and they signed a consent form. Two evaluations took place at baseline and after 12 weeks of training, consisting of 2-h sessions comprising the cognitive evaluation (1 h) and the on-road driving evaluation (45 min). The participant was given a 15-min break between these evaluations to limit fatigue effect due to the cognitive activities performed. After baseline, participants came back to the lab for their first supervised session, in 6- to 10-person groups (week 1), during which the experimenter presented the training program on the web platform. Then, participants began their computerized cognitive training at home. Two other supervised sessions (in week 4 and week 7) consisted of the presentation of normal aging and cognitive functioning. Finally, five weeks after the last supervised session (week 12), the post-training evaluation took place. Participants from the CT + DS group completed their 20-min simulator driving sessions each time they came for these supervised sessions. The experimental design is summarized in Table 1.

2.6 Statistical analyses

Statistical analyses were performed using Statistica® software. As the routes used for baseline and post-training driving evaluations were not the same, driving data (TRIP scores and penalty scores from the behavioral observation grid) were

Table 1 Overview of the experimental design with detailed content of the evaluations and interventions provided to older drivers

Nature of the evaluation and interventions	Duration	Content
Evaluation (for all participants)	- Before and after training, two hours each time	Cognitive evaluation: - Objective evaluation: TMT (A and B), DSST, and UFOV® test - Subjective evaluation (questionnaire) On-road driving evaluation: TRIP and behavioral observation grid
CT	- 36 h of computerized cognitive training during three months	Twenty cognitive exercises with fifteen difficulty levels each, focused on: attention, memory, visuospatial abilities, executive functions
CT + DS	- 35 h of computerized cognitive training during three months - 1 h of simulated driving (3*20 min)	Cognitive training: - Twenty cognitive exercises with fifteen difficulty levels each, focused on: attention, memory, visuospatial abilities, and executive functions Driving simulator experience: - Five scenarios with three difficulty levels each - Situations trained: pedestrian crossing, intersection with traffic lights, vehicle following, left-turn, and overtaking on a highway
Supervised sessions	- Three sessions: on week 1 (beginning of the training), week 4, and week 7 - 3 h each time	Informative talks about positive and negative normal aging effects and cognitive functioning

CT Cognitive training, *CT + DS* Cognitive training + driving simulator experience, *TMT* Trail Making Test, *DSST* Digit Substitution Symbol Test, *UFOV* Useful Field of View

transformed into standardized z-scores to be expressed in the same scale. Moreover, as the driving data derived from the scoring of the behavioral observation grid were positively skewed, an ln-transformation was performed. The distribution of the ln-transformed data was tested again, and analyses indicated that it did not differ from the normal distribution. Cognitive and driving data were statistically analyzed with repeated measures analysis of variance (ANOVA) using a design with 2 groups (between-subject factor: CT and CT + DS groups) X 2 time conditions (repeated measure: baseline and post-training). Then, contrast analyses were performed to compare means. Finally, regarding the calibration status, as there were no correct estimators at baseline, the changes could not be directly compared from baseline to post-training. Hence, the proportions of participants who correctly self-assessed their cognitive abilities after training were compared between groups using the Chi^2 test.

3 Results

3.1 Participant characteristics

Of the 80 expected participants included in our study, 67 finished the experiment. As specified in the introduction, this study presents some preliminary results. The data from additional participants will be presented in a forthcoming article. Of the 67 participants, 40 completed the CT (18 UEs and 22 OEs) and 27 the CT + DS program (14 UEs and 13 OEs, Table 2). Participants in the two training groups did not differ in age (t(65) = 0.88; p = 0.38) or in the time they spent on training (t(65) = 1.12 ; p = 0.27). In addition, one participant could not complete the UFOV® during the post-training evaluation because the computer was out of order.

Table 2 Characteristics of the 67 participants

	CT		CT + DS		Total
	UEs	OEs	UEs	OEs	
Number of participants	18	22	14	13	67
Age (years)	74.6 (2.7)	74.7 (4.1)	75.6 (4.1)	75.4 (4.5)	75 (3.8)
Gender	6 ♀, 12 ♂	9 ♀, 13 ♂	4 ♀, 10 ♂	4 ♀, 9 ♂	23 ♀, 44 ♂
Playtime (hours)	30.3 (10.8)		27.3 (11.2)		29.1 (11)

CT cognitive training, *CT + DS* cognitive training + driving simulator experience, *OEs* over-estimators, *UEs* under-estimators. Mean (standard deviation)

3.2 Cognitive performances

Cognitive performances in the TMT, the DSST and the UFOV® test collected at baseline and post-training are presented in

Table 3. For the TMT, a diminution in the number of perseverations was observed after training in both groups (main effect of Time, Table 4). For the DSST, the number of correct symbols increased after training, for both groups (main effect of Time, Table 4). Furthermore, for the UFOV® test, a main effect of Time was seen for the processing speed sub-score (F(1, 65) = 5.68, p = 0.02, partial eta-squared =0.08), the selective visual attention sub-score (F(1, 65) = 16.5, p = 0.0001, partial eta-squared =0.20), and for divided visual attention (F(1, 65) = 5.82, p = 0.02, partial eta-squared =0.08, Table 4). Participants from both training groups significantly improved their visual attention performance, resulting in a shorter interval presentation of the target to which they reacted accurately 75 % of the time after training at: i) the speed of processing sub-test (reduction of 28 %), ii) the divided attention subtest (reduction of 33 %), and iii) the selective attention sub-test (reduction of 14 %). However, no main effect of the Group was observed for the three UFOV® sub-scores. In addition, no Group x Time interaction was seen for the divided visual attention or selective visual attention sub-scores, but, although not significant, there was an interaction effect for the processing speed sub-score (F(1, 65) = 3.49, p = 0.07, Table 4).

3.3 Driving performances

3.3.1 TRIP grid

Results of the driving performance evaluation performed by the driving instructor by completing the TRIP grid are presented in Table 5. No main effect of the Group was observed for the TRIP total score, or for the tactical, tactical compensatory and operational sub-scores (Table 6). Moreover, no main effect of Time was seen for the TRIP total score, or for the tactical compensatory and operational sub-scores (Table 6). However, participants improved their tactical sub-score regardless of the training they completed (F(1, 65) = 5.69, p = 0.02, partial eta-squared =0.08). This result indicates that all participants anticipated the traffic and the environmental changes better. They improved their speed and lane choices and observed the safety distances from other vehicles better after training. Furthermore, no significant Group x Time interaction was found for the TRIP total score and or for the three TRIP sub-scores (Table 6). Hence, this result does not show any additional benefit of the driving simulator experience on top of the cognitive training. The driving performances of participants from both experimental groups improved similarly after training.

3.3.2 Behavioral observation grid

The Spearman correlation test revealed a negative correlation between the TRIP total score and the penalty total score both at baseline (r = −0.53, p < 0.001), and after training (r = −0.30, p = 0.01), indicating that the fitness to drive, determined by the driving instructor, is associated with driving errors, mentioned by

Table 3 Cognitive performances in the TMT, the DSST and the UFOV® test at baseline and after training for both groups

	CT		CT + DS	
	Baseline	Post training	Baseline	Post-training
TMT				
Part A – Time per transition	1.83 (0.73)	1.74 (0.60)	1.57 (0.53)	1.69 (0.69)
Part A – Correct transitions	24.00 (0.00)	23.90 (0.63)	23.93 (0.38)	23.93 (0.38)
Part B – Time per transition	3.67 (1.56)	3.68 (1.75)	3.38 (1.35)	3.10 (1.08)
Part B – Correct transitions	21.38 (4.64)	21.17 (5.42)	18.96 (6.29)	22.07 (5.24)
Part B - Perseverations	0.90 (1.58)	0.38 (0.81)	0.52 (0.94)	0.04 (0.19)
DSST				
Correct symbols	43.65 (12.69)	49.90 (12.09)	44.78 (10.32)	45.89 (10.65)
Errors	1.55 (2.09)	1.50 (1.59)	1.67 (2.30)	1.63 (2.65)
UFOV® test				
Processing speed	38.0 (33.5)	23.2 (9.6)	30.2 (18.1)	26.1 (18.2)
Divided attention	118.0 (101.6)	83.3 (92.0)	114.6 (97.2)	73.5 (69.2)
Selective attention	272.5 (113.5)	215.8 (94.9)	233.0 (90.4)	218.5 (150.5)

TMT Trail Making Test, *DSST* Digit Symbol Substitution Test, *UFOV* Useful Field of View, *CT* Cognitive Training, *CT + DS* cognitive training + driving simulator experience. Mean (standard deviation)

Table 4 Results of the ANOVA for the cognitive data

	Group main effect		Time main effect		Group X Time interaction effect	
	F (1, 65)	p	F (1, 65)	p	F (1, 65)	p
TMT – A						
Time per transition	1.21	0.27	0.06	0.80	2.07	0.15
Number of correct transitions	0.10	0.76	0.50	0.50	0.50	0.50
TMT – B						
Time per transition	1.72	0.19	0.71	0.40	0.82	0.37
Number of correct transitions	0.61	0.44	2.11	0.15	3.04	0.09
Number of perseverations	3.55	0.06	7.54	<0.01[1]	0.01	0.90
DSST						
Number of correct symbols	0.04	0.84	6.24	0.01[2]	0.72	0.40
Number of errors	0.08	0.78	0.02	0.88	<0.001	0.98
UFOV® test						
Processing speed	0.73	0.40	5.68	0.02[3]	3.49	0.07
Divided attention	0.11	0.74	16.50	<0.001[4]	0.08	0.77
Selective attention	0.69	0.40	5.82	0.02[3]	2.86	0.10

TMT Trail Making Test, *DSST* Digit Symbol Substitution Test, *UFOV* Useful Field of View

[1] Effect size: partial eta^2 = 0.10

[2] Effect size: partial eta^2 = 0.09

[3] Effect size: partial eta^2 = 0.08

[4] Effect size: partial eta^2 = 0.20

the experimenter; the better the driving instructor assesses the driving performance, the fewer driving errors will be observed.

Results from the behavioral observation grid assessing driving errors are presented in Table 7. No main effect of the Group was observed for the total penalty score, or for the sub-scores related to visual attention, interaction with other road users, lane positioning, speed adaptation, car control handling, or driving instructor interventions (Table 8). However, for the planning sub-score, the Group effect was close to the threshold of significance (F(1, 65) = 3.98, p = 0.05). Participants from the CT group tended to make more planning errors than participants from the CT + DS group, regardless of the time of evaluation (i.e. at baseline or post-training). Furthermore, no main effect of Time was observed for the total penalty score, or for any of the penalty sub-scores (Table 8). Additionally, no Group x Time interaction was identified for the total penalty score, or for the sub-scores related to visual attention, interaction with other road users, planning, lane positioning, or driving instructor interventions. This result suggests that the driving simulator experience did not influence the drivers' behavior on the road. In contrast to our hypothesis, the participants from the CT + DS group did not make significantly fewer driving errors than those from the CT group. Nonetheless, a significant Group x Time interaction was shown for the sub-scores related to speed adaptation and car control handling (Table 8). For both dimensions, these penalty sub-scores decreased after training for the CT group, whereas they increased for the CT + DS group. This result indicates that the driving simulator experience led to a deterioration in speed adaptation and car control handling performances, whereas

Table 5 Driving performances assessed with the TRIP grid at baseline and after training

	CT		CT + DS	
TRIP grid	Baseline	Post training	Baseline	Post-training
Total score (/100)	72.0 (5.0)	72.5 (3.2)	73.4 (2.6)	72.3 (3.8)
Tactical sub-score (/46)	32.7 (2.4)	33.3 (2.1)	33.2 (2.2)	34.0 (1.5)
Tactical compensation sub-score (/20)	12.1 (1.9)	12.6 (1.4)	12.7 (1.2)	12.8 (1.2)
Operational sub-score (/39)	28.5 (2.7)	29.3 (1.4)	29.2 (2.3)	29.4 (1.5)

TRIP Test Ride for Investigating Practical fitness to drive, *CT* cognitive training, *CT + DS* cognitive training + driving simulator experience. Mean (standard deviation)

Table 6 Results of the ANOVA for the driving data (TRIP grid)

	Group main effect		Time main effect		Group X Time interaction effect	
TRIP grid	F (1, 65)	p	F (1, 65)	p	F (1, 65)	p
Total score	0.58	0.45	0.27	0.60	2.41	0.12
Tactical sub-score	2.20	0.14	5.69	0.02[1]	0.10	0.76
Tactical compensation sub-score	1.81	0.18	1.66	0.20	0.36	0.55
Operational sub-score	1.41	0.24	2.59	0.11	0.86	0.37

TRIP Test Ride for Investigating Practical fitness to drive

[1] Effect size: partial eta^2 = 0.08

the pure CT led to an improvement of these driving performances. Contrast analyses performed between baseline and post-training data indicated that the decrease of driving errors for the CT group and the increase of driving errors after training for the CT + DS group were not significant ($p = 0.08$ and $p = 0.05$ for speed adaptation, respectively; and $p = 0.11$ and $p = 0.08$ for car control handling, respectively). Finally, contrast analyses at baseline revealed a significant difference between the two groups ($p = 0.01$ for both sub-scores). Hence, the interaction effect appears to be due to this baseline difference, with participants from the CT group performing worse than participants from CT + DS group, regarding speed adaptation and car control handling. After training, both groups made approximately the same average number of driving errors.

3.4 Self-assessment of cognitive abilities

After training, objective and subjective cognitive data were compared, as described in the Method section [55]. Results of cognitive calibration are presented in Table 9. This table shows that, compared with the baseline, half of the participants from the CT group and a little more than one-third of those from the CT + DS group correctly self-assessed their cognitive abilities after training. The two training programs seemed to be equally effective in correcting cognitive self-assessment bias (Chi^2 = 3,03; ddl = 2; $p = 0.22$).

CT cognitive training group, *CT + DS* cognitive training + driving simulator experience, *UE* under-estimator, *OE* over-estimator, *CE* correct estimator

4 Discussion

After three months of cognitive training, both groups significantly improved their speed of processing and visual attention. These results are in agreement with a previous study in which combined cognitive training and physical exercises improved the same cognitive functions [64]. The cognitive training in the present study contained several exercises focused on visual attention that effectively enhanced the width of the useful field of view of our participants. Hence, participants had less difficulty detecting peripheral visual information. Moreover, the non-significant Group x Time interaction effect suggests that visual attention performances of the participants from both groups improved similarly with training. Hence, the driving simulator experience, as designed in this study, may not allow additional attentional benefits, as previously demonstrated by Roenker and colleagues [42]. Performances in the UFOV® test are associated with crash risk and also road

Table 7 Driving errors at baseline and after training

	CT		CT + DS	
Behavioral observation grid	Baseline	Post-training	Baseline	Post-training
Penalty total score	58 (26)	60 (18)	48 (12)	58 (18)
Sub-scores				
Visual attention	19 (4)	25 (5)	20 (4)	25 (6)
Interaction with other road users	6 (4)	7 (4)	5 (3)	7 (4)
Planning	13 (7)	14 (6)	11 (5)	11 (6)
Lane positioning	4 (3)	2 (2)	4 (2)	2 (2)
Speed adaptation	6 (8)	3 (3)	2 (2)	4 (4)
Car control handling	4 (5)	2 (3)	1 (1)	3 (2)
Driving instructor interventions	5 (5)	6 (3)	4 (2)	5 (1)

CT cognitive training, *CT + DS* cognitive training + driving simulator experience. Mean (standard deviation)

Table 8 Results of the ANOVA for the driving data (behavioral observation grid)

	Group main effect		Time main effect		Group X Time interaction effect	
Behavioral observation grid	F (1, 65)	p	F (1, 65)	p	F (1, 65)	p
Penalty total score	1.88	0.17	0.02	0.88	0.98	0.33
Sub-scores						
Visual attention	0.25	0.62	0.001	0.98	0.46	0.50
Interaction with other road users	0.57	0.45	0.002	0.96	0.22	0.64
Planning	3.98	0.05	0.08	0.78	1.80	0.19
Lane positioning	0.25	0.62	0.02	0.98	0.40	0.53
Speed adaptation	1.02	0.31	0.15	0.70	6.96	**0.01**[1]
Car control handling	1.51	0.22	0.14	0.71	5.83	**0.02**[2]
Driving instructor interventions	1.56	0.22	0.01	0.94	0.72	0.40

[1] Effect size: partial eta^2 = 0.09

[2] Effect size: partial eta^2 = 0.08

driving performance [59, 65, 66]. Indeed, visuo-attentional disorders and reduction of the size of the visual field of view have been shown to be associated with a higher crash risk [59, 65, 66]. In these articles, the crash rate during the five years preceding the visual attention evaluation was associated with the test performances. Regression analyses indicated that older drivers who presented deficits in visual processing (and more precisely, for divided attentional tasks) were involved in more road crashes than the others. Thus, the improvement of visual attention with cognitive training is a promising result in terms of driving safety.

The objective of the hour of driving simulation added to the computerized cognitive training was to assess the transfer of cognitive training benefits to real driving situations. This study revealed that the results of the participants who underwent driving simulation in addition to CT did not differ significantly from the results of those who performed just CT. Both training programs improved the TRIP tactical sub-score, which indicated that participants improved their adaptation in terms of lane changing, safety distances, speed regulation and anticipation regarding changes in traffic or related to unexpected events. Hence, the two training programs improved executive functioning and more precisely planning and anticipation during a complex activity: driving. However, the effect size of the improvement was small, and the partial eta^2 indicated that only 8 % of the score variation could be attributed to Time (interval between baseline and post-training evaluations). Although there are currently no normative data to quantify the improvement with the TRIP tactical sub-score, a previous study showed that patients who suffered from Parkinson's disease had, on average, four points less than controls [67]. It would be useful to compare these data with findings from different populations to understand the repercussions of this one-point improvement between the pre- and post-test.

Table 9 Self-assessment of cognitive abilities of 67 drivers at baseline and after training

	CT		CT + DS	
	Baseline	Post-training	Baseline	Post-training
UE	18	5	14	8
OE	22	15	13	8
CE	-	20	-	11

In this study, the driving performance evaluation was also conducted with a behavioral observation grid, completed by the experimenter. The analyses showed a significant negative correlation between the total penalty score of the behavioral observation grid and the TRIP total score, which indicated the links between the parameters measured by these two grids. The negative correlation indicated that when the participants improved their overall driving performance, their total penalty score decreased. Complementary analysis of the behavioral observation grid revealed a significant Group x Time interaction with participants from the CT group who improved both their speed adaptation and car control handling after training, whereas participants from the CT + DS group made more mistakes in these dimensions. Indeed, after training, participants from the CT group drove less slowly and adapted their speed choice better to driving situations, whereas participants from the CT + DS group drove above the speed limit more and had more difficulty with gear shifting and engine speed. However, this significant interaction reflected a "regression to the mean" and appeared to be due to a significant difference between the CT and CT + DS groups at baseline. Nevertheless, this result went against literature findings indicating gains in visual checking strategies, lane changing and indicator use after driving simulator training [40, 42]. Contrary to our hypothesis, the driving simulator experience did not allow the transfer of training benefits to the road:

participants who drove on the simulator did not perform better on the road than those who only completed the cognitive training program. This finding contrasts with that of Lavallière and colleagues who showed an on-road transfer (improvement of the visual scanning during lane changing) of their driving simulator training [40]. Although the duration of the driving simulator experience in the present study was the same as in Lavallière and colleagues' study, its content may have been too varied (i.e. focused on many different driving situations) to be really effective. Indeed, Lavallière and colleagues focused their training on visual scanning during lane changing, whereas in the present study five driving situations were presented to the participants. We hypothesize that training gains were not seen in the present study because the duration of each driving situation was insufficient and because our design used several driving situations.

No improvement of visual attention performance during driving was seen after the training, in contrast to the improvement of the UFOV® performances. This discrepancy may be explained by the fact that in the driving situation the task was more complex than during the computerized test, so even if the size of the useful field of view of the drivers improved, it did not seem to influence visual attention assessed during driving. A previous study has shown that, in particular driving situations, the attentional demands made by driving might be too high to observe a benefit from improvement in UFOV® performance [68].

Our results suggest that the two training programs were equally effective in improving the cognitive self-assessment of older drivers. The CT program allowed half of the group to become CEs after training (20 out of 40 participants), compared with a little more than one-third for the other training program (11 out of 27 participants). As the proportion of participants who became CEs of their cognitive abilities did not significantly differ between the two groups, it seems that the simulated driving experience did not influence the calibration of cognitive abilities. We supposed that the feedback received during the training program allowed participants to gain insight into their cognitive abilities. In addition, both training programs seemed to be more effective for UEs than for OEs (21 CEs post-training out of the 32 initial UEs, versus 10 CEs post-training out of the initial 35 OEs, $\mathrm{Chi}^2 = 9.23$; ddl = 1; $p = 0.002$). Interestingly, when analyzing training compliance, no between-group difference in total playtime was noted. However, when examining each training group, we noticed that UEs trained significantly more than OEs in the CT + DS group (32 h versus 22 h, respectively), in contrast to what was found for the CT group (32 h for the UEs versus 29 h for the OEs, no significant difference between the two). One possible explanation for this difference could be that the OEs from the CT + DS group, who performed the simulated driving activity in addition to the CT, could have been more interested in driving the simulator than in the CT because they thought they did not need to train their cognitive abilities. To summarize, the training seemed to improve self-awareness of cognitive abilities for older drivers who under-estimate their cognitive abilities, probably thanks to the feedback received, which provided information on progress made. Further investigations should be conducted to determine whether the improved insight of UEs is associated with an improvement in their self-confidence or self-esteem. It would also be interesting to assess the metacognitive skills of the OEs, as it has been shown that OEs have difficulty gaining insight into their abilities because of a lack of metacognitive skills [54].

Overall, these preliminary results have not demonstrated any on-road transfer of the cognitive training benefits through the driving simulator experience. The CT + DS group did not show additional benefits in on-road driving performances. Further study could be carried out to investigate the effect on driving performance of driving-related feedback received during simulated driving sessions or during on-road training sessions. Moreover, the results seem to indicate an improvement of visual attentional abilities and tactical on-road driving performances for both experimental groups. Nevertheless, as no control group has yet been included, these preliminary results do not provide an answer regarding the effectiveness of this cognitive training program in improving the cognitive and driving performances of older drivers. Further investigations are planned to distinguish the role of the cognitive training intervention from that of the time spent participating in an experimental protocol.

5 Conclusion and perspectives

To conclude, the first results of this study show that three-month cognitive training seems to be as effective in correcting older drivers' calibration bias as the same training program coupled to a driving simulator experience. Furthermore, UEs appear to be more susceptible than OEs to this sort of training as they were significantly better calibrated after the program than the OEs (2/3 of the UEs became CEs, compared with less than one-third of the OEs). In addition, both cognitive training programs enhanced the useful visual field of view of our participants during a computerized task. Nevertheless, the visual attention as evaluated during the on-road driving test did not change after training. However, all participants showed better planning and anticipation abilities during the on-road driving test. Thus, some benefits of this computerized cognitive training could be transferred to on-road driving. Finally, note that the experiment was still in progress during the writing of this article. Hence, other participants from the CT + DS and control groups have since completed their training and further analyses will be performed to define better the effectiveness of each intervention.

A limitation of this study is that some participants felt uncomfortable when they drove the simulator. Indeed, seven participants experienced simulator sickness during the familiarization drive, which was performed after the on-road driving evaluation and before the first driving simulated session. In order to keep these participants in the protocol, they were assigned to the CT group. To avoid this kind of problem, further investigations should be conducted to identify the participants likely to be susceptible to simulator sickness before they drive the simulator.

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