

Comparison between elderly and young drivers' performances on a driving simulator and self-assessment of their driving attitudes and mastery

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Abstract

Elderly people are often considered dangerous drivers due to a decline in visual exploration and cognitive functions. The purpose of this study was to look into 18 young (between 21 and 35 years old) and 12 elderly (between 65 and 78 years old) drivers' behaviour. We compared their self-assessment of driving as well as their visual and cognitive competencies. Then we assessed their driving competencies and self-regulation practices by using different scenarios on a driving simulator. These scenarios were designed to test drivers in situations that were intended to solicit the cognitive competencies identified as problematic for elderly drivers (attention, executive functions: anticipation, planning, mental flexibility). Results could show that, although elderly drivers did not always perform as well as young drivers, they could put in place compensatory strategies which may reduce their risk of being injured and future research should explore ways of enhancing those strategies. In particular, more should be done in order to strengthen elderly's understanding regarding their driving difficulties and help them set up coping methods with respect to these difficulties.

Keywords : Elderly, driving, car crash, driving self-regulation, visual field, cognitive executive functions

I. Introduction

An increase in life expectancy and the democratization of driving licenses issued have led to an ever-increasing number of elderly drivers. It is often claimed that elderly people are dangerous drivers. Indeed, analyses of car crashes have indicated that with advancing age comes a greater risk of being involved in a car crash (Papa et al., 2014). Older people are also more likely to be seriously or fatally injured in at-fault crashes (Rakotonirainy et al., 2012; Yee et al., 2006). In this paper, we seek to analyse the reasons for an increase in crash occurrence, together with how the elderly self-report their driving habits and attitude and the coping solutions they adopt.

1.1. Cognitive decline and car crashes

The increased likelihood of being involved in a car crash is often linked with a decline in visual exploration and cognitive functions (e.g., attention, executive functions: planning, anticipation, mental flexibility) in the elderly. In terms of executive functions, Bellanger et al. (2009) showed that an unexpected event requiring multiple synchronized reactions (e.g., overtaking, pedestrian crossing, parked car incursion, and car incursion at a stop sign) leads to a higher crash rate for elderly drivers (mean = 73.4 years old) on a simulator than for younger drivers (mean = 29.5 years old). They concluded that it was more difficult for older drivers to activate several car controls simultaneously, putting them at risk when facing challenging and time-pressured road events. The attention capacity of elderly drivers has also often been questioned: for example, Thompson et al. (2012) examined distracted on-road driving performance using a concurrent auditory-verbal processing load created by the Paced Auditory Serial Addition Task (PASAT). Elderly drivers (mean = 72.5 year) showed lower levels of performance than middle-aged drivers (mean = 53.7 years) during the PASAT test. Moreover, they made significantly more at-fault safety errors during the test than middle-aged drivers, despite there were no significant differences between the groups at baseline. This suggests some effect of age on driving performance when a secondary task is introduced. Ebnali et al. (2016) showed that the elderly (65 - 83 years old) drive more slowly and that older drivers (75 years old and above) increase speed variability when they are engaged in a cognitively demanding dual-task when driving, like listening to the news on the radio. Moreover, although overall comprehension of the news did not differ between young (mean = 31.5 years old) and old drivers, the more in-depth comprehension of the news did decline considerably for elderly

drivers. This result indicates that attentional capacities are limited, thus avoiding a deep processing of the information.

According to Horswill et al. (2008), this deterioration in cognitive function may have a negative impact on elderly drivers' hazard perception. The predominant decline observed among elderly drivers includes general cognitive slowing and task-switching deficits, all of which may have consequences for hazard perception. Other tests used by the authors include the Trail Making Test (TMT) to assess executive functions and visual attention, and the Useful Field Of View (UFOV) test to assess visual cognitive factors and visual attention, and a simple test of reaction time. The results of these tests were seen to be significantly correlated to hazard detection. They also showed that older people (65-84 years old) are less successful in detecting danger - i.e. a significant positive correlation was observed between age and hazard perception response time - and that performance fluctuations among this population are correlated with their performance on the three previously named tests. Sakai et al. (2015) showed that UFOV is a good predictor of at-fault crash risk among elderly Japanese drivers. For a meta-analysis of the utility of this test in predicting driving performance in older adults see Ball et al. (2005).

1.2. Self-regulating behaviours

Cognitive decline takes place over a long period of time. Thus, elderly drivers have enough time to set up adapted avoiding behaviours - i.e. behaviours that avoid facing particularly stressful situations or situations that have become difficult to manage due to cognitive decline - for example, by avoiding choosing a road route through the city during rush hour. Moreover, they also benefit from lengthy driving experience, during which time they have learned to develop compensatory strategies - i.e., adapted and safe behaviour when faced with a variety of hazardous situations - for example, increasing the safety distance from the vehicle in front when reflexes decrease. These behaviours can be grouped under the term of "self-regulating behaviours" (for some examples see Table1). In the rest of this section we will consider various examples in the literature regarding the implementation of these behaviours. Data obtained from an on-road study carried out by Reimer et al. (2013), noted that French drivers aged between 60 and 69 years old were less likely to change lane and drive in the leftmost lane than younger drivers (20-29; 40-49). Charlton et al. (2013) carried out a study based on self-reported aberrant driving behaviour using a Swedish version of the driver behaviour questionnaire. They found that elderly drivers self-regulate by engaging less frequently in secondary tasks (e.g., scratching/grooming, talking/singing and manipulating the vehicle control panel) when the driving task is more challenging. In this way, they reduce the

cognitive cost of sharing attention between the two tasks. Interestingly, Baldock et al. (2006) considered the characteristics of self-regulation when driving and their relationship to driving ability among older adults. Poorer performance of elderly drivers in the driving test was not related to overall avoidance of difficult driving situations. In fact, driving ability is mostly associated with the avoidance of difficult driving situations in which drivers had low confidence.

Thus, if the evidence supports the view that drivers with cognitive impairment do restrict their driving to avoid complex driving situations (for a review, see Devlin & McGilivray, 2014), can we conclude that these behaviours are the result of a true awareness of their poorer driving performance? Using a self-reported questionnaire, Rimmo and Hakamies-Blomqvist (2002) reported that older drivers adjust their driving performance in response to their health and to problems they experience while driving. Meng and Siren (2012) showed that the self-recognition of cognitive problems was associated with improvements in higher level driving skills and a decline in lower level driving skills. The lower levels include skills such as vehicle manoeuvring and knowledge of basic rules, while the higher levels include skills such as strategic decision making, self-monitoring, and social interaction in traffic. Moreover, cognitive problems were associated with discomfort in, and avoidance of some driving situations. A linear relationship between driving discomfort and avoidance was found and this tended to be stronger for drivers who recognize they have cognitive problems. These results suggest that driving-related discomfort is an important factor in the self-regulation of driving.

Nevertheless, the above study did not compare the subjective feelings of older drivers with an objective assessment of their cognitive difficulties. Horswill et al. (2011) sought to fulfill this by comparing elderly drivers' assessment of their performance in a video-based hazard perception test (ACT Hazard Perception Test; Wetton et al., 2010) with their actual performance. They observed that elderly drivers were less able to assess their own performance at the test. Thus, an age-related decline in hazard perception latency was not reflected in the drivers' self-assessment. Nonetheless, the self-assessment of test performance was correlated with self-reported regulation of driving, as was self-rated driving ability. Thus, whilst drivers may use self-assessment of their driving ability to determine the degree to which they restrict their driving, they still have little insight into their own driving ability. This is consistent with the findings of Wong et al. (2012), who showed that older drivers' self-regulating behaviour was more strongly related to self-perceived driving abilities than to objective driving abilities. Furthermore, drivers who demonstrated greater discrepancies between driving confidence and actual abilities (indicating lack of insight) were less likely to self-regulate their driving. Sakai

et al. (2015) also showed that elderly drivers had a poor self-assessment of cognitive capacities. Their performance in a visual and attentional test (Useful Field of View UFOV) was not correlated to the self-evaluated driving style of elderly drivers. From these results, therefore, self-regulation seems to be related more to a general feeling about driving difficulties than to a true awareness.

/Insert Table1 about here/

1.3. Efficiency of self-regulating behaviour

Another important question is whether the establishment of self-regulation strategies by elderly drivers is sufficient to reduce the risk of car crashes. Ross et al. (2009) showed that drivers at risk of subsequent crashes, based upon UFOV results, regulated their driving more than the lower-risk participants. Despite self-regulation, a larger sample of these older drivers caused at-fault crashes within the two years following the UFOV test than those in the not-at-risk group. This could perhaps be explained by a lower estimation of actual cognitive difficulties (Horswill et al., 2011; Wong et al., 2012) and choice of inappropriate behavioural adaptation, as we mention in the previous section. It has effectively been shown that providing feedback on cognitive and/or visual ability to drive safely is predictive of change in driving self-regulation. For example, Achkerman et al. (2010) showed that feedback about UFOV performance was predictive of self-rated driving avoidance - i.e., driving at night, during bad weather, in rush hour traffic, in unfamiliar areas, or making left turns across oncoming traffic - whilst self-rated exposure (number of days per week driven and miles driven per week) and self-rated driving ability (based on one question: "How would you rate the quality of your driving?") were unaffected. This indicates that drivers selectively adapt their driving to the identified difficulties (attention default and the detection of unexpected events). Nevertheless, Ebnali et al. (2016) showed that appropriate behavioural adaptation is sometimes not enough to entirely compensate for drivers' cognitive difficulties. In their study, the adoption of a safety margin to some extent compensated for elderly drivers' performances when they were cognitively engaged in a secondary task like listening to the news on the radio : mean speed reduction, reduction in overtaking activities and reduction of the duration of driving in the unsafe-zone. This strategy allows a safety margin to be retained and relieves cognitive capacities (attention), allowing drivers to deal with the secondary task. In this regard, the strategy can be seen as efficient and yet, the in-depth processing of information is still affected by the secondary task, showing the limits of behavioural adaptation. Similarly, Thompson et al. (2012) suggested that elderly drivers exhibit a more time-pressured and vigilant steering

strategy during the PASAT compared with the more confident or relaxed strategy adopted by middle-aged drivers. Unfortunately, changes in elderly behaviour did not result in fewer accidents during the on-road evaluation.

I.4.Problematic

All the studies presented in the introduction offer a better understanding of driving practice in elderly drivers. Nevertheless, many of these studies founded their estimation of elderly behaviour on data obtained thanks to surveys based on self-rating questionnaire or crash data (Achkerman et al., 2010; Horswill et al., 2008; Meng et al., 2012; Rakotonirainy et al., 2012; Rimmo et al., 2002; Ross et al., 2009; Sakai et al., 2015; Won et al., 2012; Yee et al., 2006). This gives very interesting information about elderly drivers' estimation of their own competencies but it also has limitations in the sense that people's objectivity can often be questioned as soon as it concerns their self-report and more particularly when it comes to a less rewarding behaviour. In this case direct observation of the driving behaviour is missing. On the contrary, some other studies directly considered the impact of a cognitively- demanding dual task in real driving conditions (Ebnali et al., 2016; Reimer et al., 2013; Thompson et al., 2012) or they adopt a monitoring protocol to identify certain driver behaviours (engagement in distracting behaviours) in real driving conditions (Charlton et al., 2013), but without considering driver self-report. One study (Baldock et al., 2006) compared the performance on-road to the result of the self-assessment questionnaire about driving habits and attitudes but without considering the cognitive impairment of elderly. Finally, one study used a driving simulator to expose drivers to various challenging situations but without considering drivers' self-assessment of their driving competencies. Thus, none of all the considered studies investigated at the same time:

- 1- a measurement of cognitive abilities and self-assessment of self-regulating behaviour and driving performance,
- 2- an objective measurement of driving abilities in conditions requiring the cognitive abilities (previously measured) and, at the same time, challenging (without any danger) the capacity to react to hazardous situations,
- 3- an objective assessment of self-regulating behaviour (speed limitation, avoidance of certain driving conditions, ...).

In this study, our objective was to set up an experimental protocol which compared elderly and young participants on all of these dimensions. We hoped thus to obtain a better

comprehension of these two populations, resulting in the suggestion of strategies to help older drivers recognize their limitations and then cope with them.

Thus, we created a questionnaire to self-assess the driving habits and attitudes of young and elderly drivers. Then, we used a driving simulator to compare the competencies and self-regulation adopted by these two groups of participants. Different scenarios aimed at testing drivers in situations which were supposed to solicit visual and cognitive competencies that have been identified as problematic for the elderly drivers. We chose to use a driving simulator because it allowed us to systematically compare the same events and driving conditions for all the participants. This tool allowed us to precisely manipulate driving condition and event occurrences on the road, enabling us to compare situations and design events with greater precision. Moreover, the validity of the simulator as a useful tool for an initial evaluation of driving competencies no longer needs to be demonstrated (Milleville-Pennel & Charron, 2015). In particular, it can help avoiding the kind of stress which can lead to task failure or a deterioration in performance. Thus, we created a specific driving test to assess elderly drivers' performances in an urban environment so that we were able to selectively test each specific cognitive function involved in driving - i.e. attention, anticipation, mental flexibility and reaction time - and brought into play by different critical events that occurred along the road (see method section 2.2.1.3.4.). A second driving test was created to assess elderly drivers' cognitive competencies, and, more specifically, executive functions (namely, planning, information search and mental flexibility) through the re-planning of itinerary which was unexpectedly changed by the appearance of roadworks (see method section 2.2.1.3.3). These scenarios also allowed to assess some self-regulation behaviours such as speed limitation in high demanding conditions or avoidance of some situations often perceived as difficult to manage (for example, driving in an unknown city during peak hours).

We also chose to create our own test to assess visual attention while driving. The test usually used (UFOV) provides an assessment of visual attention in static conditions and it does not mean that the driver is tested in real road conditions. Thus, we created a test of visual field of view which allowed us to compare the participant field of view in static and dynamic conditions (while driving). Differences in performance between the two conditions allowed us to assess any decline in performance resulting from a change in the driving task (see method section 2.2.1.3.2.). Moreover, this test offered an accurate assessment of the size of the visual field in the actual visual environment in which the driver was tested about his driving competencies (Milleville-Pennel, Mars, Zanlonghi, Rozière & Barrucand, 2018). Mental flexibility

and cognitive load were also assessed using a dedicated test (see Method section 2.2.1.2) in order to consider cognitive decline.

Thanks to this study, our aim was thus to compare elderly and young drivers' competencies using a driving simulator in order to assess at the same time their cognitive functions when solicited by the driving activity, their behaviour in various situations of driving, their visual field of view in a dynamic and realistic driving situation and their self-assessment about their driving competencies.

2. Method

2.1. Participants

Thirty participants took part in this study: 12 elderly people (6 men and 6 women) aged between 65 and 78 years; 18 young people (7 women and 11 men) aged between 21 and 35 years. All of them had normal or corrected-to-normal vision (they wore glasses). They were all volunteers and were informed of the experiment's actual purpose. Each of them had driving experience of more than three years. They all drove on a regular basis and half of them drove at least 2500 km per year and at least 10km per week. Our sample of elderly people was not atypical of French population as according to the prospective cohort study of Marie Dit Asse, Fabrigoule, Helmer, Laumon & Lafont (2014), 44.55% of drivers over 65 years of age (out of a cohort of 523 French participants) drove more than 50km/week and 55.45 % drove less than 50km per week. In our sample 58.33 % of the elderly and 50% of the young participants drove between 10 to 50km per week and 41.67 % of the elderly and 50% of the young participants drove more than 50km per week.

2.2. Apparatus and procedure

2.2.1. Apparatus

A main overview of the tools used and the analysis conducted is presented in Table 2.

/Insert Table 2 about here/

2.2.1.1. Questionnaire on driving behaviour

This questionnaire contained 30 questions and allowed us to assess:

- Part A: 11 questions about factual information concerning the participant (age, year of birth, gender), driving experience (year of driving license, how many years they had held a driving license, distance driven per year, distance driven per week, driving frequency in the

city, driving frequency on national roads, driving frequency on expressway, driving frequency on highways).

- Part B (table 3): 19 questions about driving behaviour and how they felt about driving. The questions were defined so that a high score in these questions meant a high speed (in Town, National Road, Highway and Expressway) and accelerations, a small distance from the vehicle in front, a high Enjoyment in taking risk behind the wheel, a high tendency in Forcing lane change, a higher Relative Speed with respect to the other drivers, more Offences reported on the road, a very Careful Driver, and a high Compliance to Road Sign and Weather conditions, a high pleasure while driving, a high feeling of being at the mercy of events, a high feeling of event and driving mastery, and low stress and effort.

All the questions contained in the questionnaire were pre-tested by a group of 10 participants to ensure that they were clear and properly understood.

/Insert Table 3 about here/

2.2.1.2. TMT A/B and Nasa TLX

The Trail Making Test (TMT; Army Individual Test Battery, 1944 [Tombaugh, 2004]) is composed of two subtests: part A and B. The Trail Making Test Part A is a measure of speed of visual and motor processing. Part B is a measure of the speed of visual and motor processing, sequencing and mental flexibility (Sprenen & Strauss, 1998). It requires participants to manually track between an alternating series of letters and numbers. This test is also highly correlated with driving (Elkin-Frankston et al., 2007). The American Medical Association (AMA) has recommended the use of the TMT when evaluating driving competencies (Wang et al., 2003).

The task load index (NASA-TLX; Hart & Staveland, 1988; Cegarra & Morgado, 2009) is a subjective, multidimensional assessment tool which rates perceived workload in terms of six dimensions: mental demand, physical demand, temporal demand, effort, frustration and performance. This is a paper and pencil task. At the end of the main task, the participant scores each dimension from 0 to 100. These six dimensions are then displayed in pairs, and the participant selects the dimension that contributed the most to her/his load. A pondered score is then obtained (the score was pondered by the number of times each dimension was chosen in a list of 15 double-choice combinations of the six dimension - see Hart & Staveland (1988) for a description of the method - for each dimension as well as a global score (which is an average of the scores for the six dimensions).

2.2.1.3. Driving simulator

The study took place in a fixed-base driving simulator consisting of a single-seat cockpit with full instrumentation. It was equipped with an active steering system for realistic force-feedback. The SCANNeRII software package was used with the CALLAS dynamic vehicle model (Lechner et al.,1997). The virtual environment was displayed on three LCD 32- inch monitors, one positioned in front of the driver and two lateral monitors turned at a 45° angle from the one in front and covering 120° of visual angle in width and 90° in height (Fig. 1). The graphics database reproduced a rural or urban environment, depending on the scenario under consideration. The simulator was coupled with an eye-tracker (Smarteye Pro5^R).

/Insert Fig.1 about here/

2.2.1.3.1. Scenario: Introduction to rural environment

This scenario consisted of a rural journey of approximately 5 min in duration. It was designed to help familiarize the participants with the driving simulator. The context of the journey was favourable: daytime driving in good weather with smooth traffic circulation (cars, bicycles and motorbikes).

2.2.1.3.2. Scenarios: Measurement of the visual field

These scenarios were built in collaboration with the Visual Centre (Clinic Jules Verne, Nantes) and were initially designed to assess the size of visual field of patients suffering from a visual field deficit (Zanlonghi et al., 2017). The first scenario, entitled *Static Visual Field* (SVF), corresponded to the standard field of view which is clinically performed during an ophthalmological assessment: head and eyes fixed (facing straight ahead toward a central fixation point), the participant had to report when he/she detected the display of a bright spot on a grey background. The points, displayed successively, were defined by their angular coordinates with respect to the central fixation point. The grid consisted of 104 points, corresponding to the 85 points of the Esterman (1982) grid, plus a further 19 points in the central zone (Fig. 2). This scenario made it possible to characterize the participant's static visual field deficit. The different points were displayed randomly on the three screens of the driving simulator. The duration of this scenario was approximately 5 min.

The second scenario, *Dynamic Visual Field* (DVF), used the same visual field test, adding a nominal driving task on a road consisting of a series of turns without other users and with an unobstructed view. The points were then displayed randomly on the three simulator's

screens while juxtaposing themselves to the road scene. The participant was free to move his/her head and eyes, and to drive at the speed he/she wanted (limited by the program up to 70km/h). The objective was to compare the results of the static visual field measurement with those obtained under driving conditions, allowing us to detect visual compensation behaviours (for example, an increase in the visual scene exploration needed to accurately detect the visual points). The duration of this scenario was approximately 5 min.

/Insert Fig.2 about here/

2.2.1.3.3. Scenario: Spatial orientation on the road

In this scenario, participants had to drive to a restaurant and then return to their starting point, Marselac Manor. This scenario tested:

- The participants in a **real situation of itinerary planning and then orientation in a town**: a map of the town and its surroundings was visualized before starting, and the most important landmarks on the road were clearly indicated. The participants then had to orient themselves in the town with the help of road signs.
- The participants' **self-regulating behaviour** through the choice of route. After finding the hostel (via a single simple route), participants had the choice between two routes: a national road, which was a longer route but in a rural area (*Countryside*), so supposed to be less restrictive and attentionally demanding; or via Marselac town centre, a shorter route but in an urban area at rush hour (*City*), which implies more complex driving situations. The choice of one of these solutions was intended to reveal the strategy followed by the driver: either shorter travel timing or the avoidance of a supposedly more complex situation - i.e. city centre streets at rush hour. Speed during the scenario was also considered as an indicator of self-regulating behaviour.
- The participants' **mental flexibility**: Whatever the initial choice, a second choice was then offered: following the initial route but with roadworks (*roadworks*) - i.e. with slowing traffic - or a longer route but avoiding the roadworks (*detour*). In the latter case, this involved questioning the route initially planned. In this case, the executive functions, particularly mental flexibility (initially evaluated with the TMT A/B) were strongly solicited.

In all, four routes were possible (Fig. 3):

- 1: *Countryside* and *detour*

- 2: *Countryside and roadworks*
- 3: *City and detour*
- 4: *City and roadworks*

The duration of this scenario was approximately of 9 min.

/Insert Fig.3 about here/

2.2.1.3.4. *Scenario: management of critical event*

During this scenario, drivers followed the path indicated by GPS (audio and visual indications). This scenario set up potentially accident-causing driving situations, but only if the participants did not produce the appropriate behaviour at the right time. None of the situations led to an accident under normal driving conditions. This scenario took place in town, with six critical events appearing at different locations on the course (each event always occurred at the same location on the road for all participants; Fig. 4a and b):

- Events implying reaction time. Three events were implemented as a function of the way reaction time was assessed. The first was a “pure test” of reaction time whereas the other ones allowed to use anticipation to be prepared to react to the event:
 - **Sudden brake event:** The vehicle in front of the driver was braking suddenly at the same time as the driver looked down at his speedometer (as indicated by the eye-tracker). This situation allowed to test the driver’s processing speed. **This event corresponded to a test of “pure reaction time”**. Effectively, in this condition, it was impossible to anticipate what would happen. The eye-tracker was used to trigger the braking as soon as the driver looked at the speedometer area. To ensure that it was always happening at the same time, a message was displayed at the bottom of the central screen to encourage the driver to look at his speedometer.
 - **Bus event:** While the driver was moving in the left lane to pass a stopped bus in the right lane, a pedestrian (who was hidden by the bus) suddenly appeared in front of the bus and crossed over in front of the driver's car. If the driver correctly detected the pedestrian when he appeared then it was easy to avoid the accident by slowing down or braking, depending on the driver’s speed. **Main cognitive functions solicited: visual exploration, anticipation, processing speed.** In this case it was possible

to anticipate what would happen based on the usual behaviour of pedestrians when they get off a bus. This was all the more so as the event occurred in the central part of the visual field.

- **Child event:** A child who was waiting on the side of the sidewalk (located at the right of the road), suddenly crossed the road a few meters in front of the driver to follow his ball that was rolling on the road. At the legal speed (50 km/h), if the driver had correctly detected the child when he started crossing the road then it was easy to avoid the accident by braking. **The main cognitive functions solicited, were: visual exploration, anticipation, processing speed.** In this case, it was possible to anticipate what would happen by using knowledge of children's usual behaviour (crossing to follow a balloon without considering the danger around them). Under these conditions, the event was initially visible in the peripheral part of the visual field. So, in case of an impairment of the peripheric visual field, it was possible that the detection be slowed.
- Events implying anticipation and visual exploration to get information about what happened all around the car, before making a decision:
 - **Motorcycle event:** The driver had to avoid a car which had stopped in the right lane while at the same time a motorcycle was trying to pass him/her on the left. If the driver had correctly detected the motorcycle in the left rear-view mirror of the car and waited for the motorcycle to catch up with him and pass him, there could be no accident. **Main cognitive functions solicited: visual exploration, anticipation.**
- Events allowing to test the driver's tendency to comply with driving and safety rules on the road:
 - **Turn left event:** The driver had to turn left with heavy traffic coming from the front at 90 km/h. The driver had to choose between passing after all the vehicles in the queue (maximum safety) or chosen to turn before the passage of the last vehicle in the queue (the time interval was quite short and the driver had just time enough to pass). **This event allowed to assess the driver's tendency to show risk-taking behaviour.**
 - **Wheelchair event:** A wheelchair pedestrian was passing slowly on a pedestrian crossing, in front of the driver. The pedestrian was so slow

that the light was turning green for the driver before the pedestrian had finished crossing the road. The driver had thus to choose between moving on and cutting the route to the pedestrian or waiting for a long time before the light turned green once again for him. **This event allowed to assess the driver's tendency to show compliance to road signs or to commit offences on the road.**

The duration of this scenario was approximately of 5 min.

/Insert Fig.4 about here/

2.2.2. Procedure

Each participant was clearly informed about the objectives and the course of the study before being asked to sign the consent letter to participate in the study.

The duration of the experimental phase was of about two hours and proceeded as follows:

- Presentation of the experimental device and reading of the instructions.
- Administration of the TMT A/B and the questionnaire on driving behaviour.
- Adjustment of the eye-tracker.
- Performance of the five driving scenarios. A pause was offered at the end of each scenario.
- Administration of the NASA TLX.

3. Results

An overview of the main results is proposed on table 2.

3.1. Cognitive decline (Nasa TLX and TMTA/B)

3.1.1. Nasa TLX

The mean score of mental workload was not statistically different between young and elderly participants (respectively 479.28 and 537.5 $t=1.02$; $p>0.05$). Nevertheless, if we consider how this mental workload was distributed among the six dimensions of the scale (Fig. 5), it appears that the two groups of participants differed with regard to the size devoted to mental demand and physical demand (respectively $t=2.05$ and $t=2.87$; all $p<0.05$). **The part of the mental workload devoted to mental and physical demand was higher for the elderly than for the young participants.**

/Insert Fig.5 about here/

3.1.2. TMT A/B

The elderly participants were slower in terms of visual and motor processing (assessed by the TMT A, respectively, for the young and elderly participants: 25.22s and 38s; $t=4.21$; $p<0.001$). In terms of mental flexibility, as measured by the TMT B-A, the elderly participants also gave poorer performances than the young drivers (respectively, for young and elderly participants: 25.11s and 57.25s; $t=4.51$; $p<0.001$). **Therefore, we can conclude that elderly drivers were more affected by the constraints of switching between the two tasks than young drivers.** Nevertheless, the elderly drivers' performances at the TMT were no worse than those considered to be standard for their age group (Fig.6; Tombougt, 2004; Horswill et al., 2008; Horswill et al., 2009).

/Insert Fig.6 about here/

3.2. Visual field of view

The size of the visual field of view of the two groups did not differ in static conditions ($t=0.95$; $p>0.05$) and covered 99.8% of the visual zone tested. A degradation of the visual field was observed for the two groups in driving condition (respectively, for young and elderly participants $t=2.87$ and $t=4.66$; $p<0.001$). Nevertheless, the degradation was higher for elderly participants than for young participants (respectively, 8.25% and 17.25% for young and elderly participants, $t=4.25$; $p<0.001$). In order to determine which area of the visual field was affected by the driving task, the visual field was divided into seven visual areas: from 1: the central zone to 7: the most remote area (Fig. 7). For young participants, the impairment was limited to areas 7 and 6. For elderly participants, the impairment sometimes extended into zones 5 and 4. **In any case, only the peripheral region of the visual field was impacted by the driving task and this impairment was higher for elderly.**

/Insert Fig.7 about here/

3.3. Driving practice (part A from the driving behaviour questionnaire)

Unsurprisingly, the results of the questionnaire about *driving behaviour* indicated that the elderly participants had a longer experience of driving (mean of 50.4 years) than young drivers (mean of 6.8 years, $t=24.05$; $p<0.001$). Nevertheless, there were no statistically significant differences in terms of the distance driven per week ($t=1.36$; $p>0.05$) or per year ($t=1.05$; $p>0.05$). The same was also true for the type of roads they usually drove on

(respectively, for Town, A-Road, Fast track and Highway, $t= 0.74$, $t=1.08$, $t=0.87$ and $t=0.72$; all $p>0.05$).

3.4. Reported driving behaviour (part B of the driving behaviour questionnaire)

3.4.1. Scale validity

In order to determine the relevance of the questionnaire and identify the underlying dimensions which allowed the variables to be grouped together, a PCA (Principal Component Analysis) was carried out. In order to limit the number of variables in the analysis and to obtain an interpretable PCA, a first selection was carried out to identify the relevant variables to be retained. The question, *Feeling of being at the mercy of events* was removed from the analysis, as it was very redundant with the question *Feeling of event mastery*. It was the same concerning the questions about the two intermediary speeds named *Speed on National Road* and *Speed on Expressway*. A PCA was therefore carried out with 16 variables and 30 observations for each variable (table 2). The PCA highlighted two main dimensions, each explaining 31.99% and 16.51% of the total variance (Fig.8 and Table 3).

/Insert Fig.8 about here/

The correlation circle showed that the variables named *Forcing lane change* and *Pleasure*, did not have a significant correlation with the other variables considered in the analysis because these variables were close to the centre of the circle. They were therefore not retained for further analysis.

Moreover, we saw that the variables *Speed in Town*, *Speed on Highway*, *Acceleration*, *Distance from the vehicle in front*, *Enjoyment in taking risk behind the wheel*, *Relative Speed with respect to the other driver*, *Offence reported on the road* and *feeling of event mastery* were close to each other but also close to the periphery of the circle, so we assumed that the underlying variables were significantly correlated with each other. Concerning the variables *Careful Drive*, *Compliance to Road Sign*, *Compliance to Weather*, they were also significantly correlated with each other.

Finally, we saw that these first two groups of variables were opposed and therefore negatively correlated. All these variables were associated with the same dimension (dim1, see Table 4). In addition, on the whole of the first group of 8 questions we could obtain a Cronbach alpha of 0.85. The second group of 3 questions got a Cronbach alpha of 0.76. As these were two groups of variables being correlated to the same dimension, we grouped them into an

indicator called *Driving Style* (DriSty) by adopting the following formula for each driver: $((\text{SpeedTo} + \text{SpeedHi} + \text{Acceleration} + \text{DistVeh} + \text{Risk} + \text{RelSpeed} + \text{Offence} + \text{EMastery}) + (100 - \text{CareDri}) + (100 - \text{RoadSignCom}) + (100 - \text{WeatherCom})) / 11$. We considered that the closer the indicator was to 100, the less cautious driving style the driver had. The 3 last variables were inverted in the formula in order to avoid that the negative correlation changed the Cronbach Alpha computed for all of the 11 variables grouped in this way. We thus obtained a Cronbach Alpha of 0.86.

Finally, the variables named *Feeling of driving task master*, *Stress and Effort*, were also strongly correlated with each other, but this last group of variables was rather perpendicular to the other two first groups, which suggested that the underlying variables were independent. The PCA showed that this group of variables was correlated with the second dimension identified in the analysis (Table 4). In addition, we noted a Cronbach Alpha of 0.76 for these 3 variables. So, we grouped them together to form the *Feeling while driving* (DriFeel) indicator by adopting the following formula for each driver: $(\text{Stress} + \text{Effort} + \text{DMastery}) / 3$. The closer the indicator was to 100, the more positive the driver felt when driving: little stress and effort and high feeling of driving mastery.

/Insert Table 4 about here/

3.4.2. Comparison between elderly and young drivers on each variable of the driving behaviour questionnaire

The table 5 shows the results of the statistical comparisons between the two groups for each variable. There was a statistically significant difference between the elderly and young drivers regarding the *Driving Style* (and it was the same for each variable considered individually, except *Risk* and *CareDri*) but not concerning the *Feeling while driving*.

/Insert Table 5 about here/

A PCA was then computed integrating the age as a new variable in order to assess the link between this variable and the 14 other ones considered in the driving behaviour questionnaire. Thus, we conducted a PCA with 15 variables and 30 observations for each variable. The PCA (Fig. 9a) showed that age was not correlated with the variables forming the *Feeling while driving* indicator but was negatively correlated with the variables forming the *Driving style* indicator. Fig. 9b shows (in the form of blue vectors) the position of the *Feeling*

while driving and *Driving style* indicators on the two main dimensions identified in the PCA. These variables were considered as additional variables during the PCA in order not to influence the variance calculations. Results of the PCA showed that, **as age increased, drivers tended to report that they decreased their speed (*SpeedTo* and *SpeedHi*), did less abrupt acceleration (*Acceleration*), increased the distance to the vehicle in front (*Distveh*), enjoyed less taking risks (*Risk*), decreased their speed compared to other vehicles (*RelSpeed*), did fewer infractions (*Offence*), were more cautious (*CareDri*), had a lower appreciation of their driving and less sense of control over what is happening on the road (*EMastery*), adapted more their driving to driving conditions (*RoadSignCom*, *WeatherCom*). On the other hand, results confirmed that the feeling while driving (at least which concerns our sample of participants) was not correlated with age. Thus, despite elderly drivers reported adopting a safer behaviour and feeling less confident in event mastery, they did not report more stress or effort while driving than did young drivers and they stayed confident in their driving mastery.**

/Insert Fig.9 about here/

3.5. Behaviour on the driving simulator

3.5.1. Management of conflicting situations and orientation in town (scenario *Spatial orientation on road*).

In terms of the first choice made by participants (town or countryside), the two groups did not differ ($\chi^2(1, N=28)=2.07$; $p>0.05$). With respect to the second choice (diversion or roadworks), more elderly participants chose roadworks than young participants ($\chi^2(1, N=28)=43.56$; $p<0.05$) and fewer ones chose the diversion ($\chi^2(1, N=28)=43.56$; $p<0.05$). **Thus, this could indicate that they did not show self-regulating behaviour by avoiding town but they did show a less flexible behaviour.**

When they tried to orient themselves in the town and find the two destinations, **none of the two groups made mistakes**. Nevertheless, the elderly drivers took more time to perform the task than their younger counterparts (mean time respectively for young and old drivers: 9.77mn (SD 0.81) and 12.53mn (SD 1.90); $t=5.41$; $p<0.001$). This increase in time might be explained by the fact that elderly people tended to drive slower on this sort of road (mean speed respectively for young and elderly: 27.33 km/h (SD 2.25) and 22.80 (SD 2.10); $t=5.40$;

$p < 0.001$). **Thus, we could assume that elderly drivers needed more time to read signs and orient themselves on the road.**

On the contrary, the mean speed variability was less important for elderly than for young drivers (mean speed variability respectively for young and old drivers: 12.61 km/h (SD 1.24) and 10.10 (SD 1.52); $t = 4.92$; $p > 0.01$). **Thus, elderly drove slower and with less important periods of acceleration and braking. Considered together, these variables indicated a less nervous driving style and could indicate a self-regulating behaviour.**

3.5.2. Behaviour on the road (scenario *management of critical events*)

The speed of elderly drivers in the town did not differ from the one of the young drivers ($t = 5.41$; $p > 0.05$). This result could appear to be inconsistent with the result observed in the spatial orientation on the road scenario, where the speed differed between the two groups. However, in this condition, the use of GPS avoided the need to look for and read signs. **Thus, this result confirmed the supposition that, in terms of spatial orientation on the road, the elderly needed more time to read signs and orient themselves on the road, so speed limitation in this scenario could be considered as a self-regulating behaviour.**

Concerning critical events, some of them led to different reactions that were categorized according to the level of dangerousness. For example, concerning the *Turn left* event, the driver could decide to pass after all the vehicles in the queue (maximum safety) or choose to turn before the passage of the last vehicle in the queue (the time interval was quite short and the driver had just time enough to pass). **Elderly drivers had fewer dangerous behaviours than young participants** if we consider all the critical events that could prompt two or more possible choices in the management of the event, including one that was dangerous (*Motorbike event*, *Wheelchair event* and *Turn left event*; ($\chi^2(1, N=26) = 6.1$; $p < 0.05$). This finding was most likely because of the less risky behaviour adopted by elderly drivers during the *Motorbike event* ($\chi^2(1, N=26) = 5.3$; $p < 0.05$).

In terms of the management of other critical events, we considered the reaction time when it was necessary to brake in order to avoid the event: *Child event*, *Bus event* and *Sudden brake event*. No significant difference was observed between the two groups concerning the *Bus event* ($t = 1.35$; $p > 0.05$), but the elderly participants were slower to brake for the *Child event* [mean reaction time respectively for young and old drivers: 1.28s (SD 0.31) and 1.73s (SD 0.31); $t = 2.94$; $p < 0.01$] and *Sudden brake event* [mean reaction time respectively for young and old drivers: 1.29s (SD 0.32) and 2.30s (SD 0.42); $t = 5.78$; $p < 0.01$]. **This indicated longer**

reaction time for elderly participants. Nevertheless, none of the participants were involved in an accident on the driving simulator.

3.6. Relation between Age and some of the indicators considered in the study

In order to determine the correlation which could exist between the *Age* of the drivers and some of the different indicators we considered in the study, a PCA was conducted with the following 10 variables : *Age*, *DriStyle*, *DriFee*, *TMT* (we considered de TMT B-A indicator of mental flexibility), *NasaTLX* (mean score of mental workload), the size of the visual field in static (*VFStat*) and dynamic (*VFDyn*) conditions and the maximum speed on the driving simulator as measured in the scenario “*Spatial orientation on the road*” (*SpeedMaxRO*) and “*management of critical events*” (*SpeedMaxCE*). Finally, the reaction time (*RT*) was also considered. We only included the data implying “pure reaction time measurement” which is the reaction time measured in the sudden brake event. Speed and reaction time were the only variables measured on the driving simulator which could properly be considered in the PCA. The results of the PCA, as represented by the circle of the correlations (Fig. 10a), showed that *Age* was significantly and positively correlated to *TMT* result and *RT* whereas it was significantly and negatively correlated to *VFDyn*, *DriStyle* and the *SpeedMaxRO* on the driving simulator. Thus, **the older the participants of this study were and the worse they were on TMT test (that is to say the worse was mental flexibility), the higher was their reaction time, the smaller was the size of their visual field in dynamic conditions, the more they reported a cautious driving style and the slower they drove on the driving simulator when they had to look for road sign indications.** Concerning the *SpeedMaxCE*, it was not correlated with the variable we considered in the study except the *SpeedMaxRO* as confirmed by the correlation graph (Fig. 10b). NASA TLX appeared not to be correlated with age and the other variables considered. The two last variables (*DriFeel* and *VFStat*) were not well represented on the circle and didn’t seem to lead to any significant correlation with the other variables considered. This was confirmed by the correlation graph (Fig. 10b).

/Insert Fig.10 about here/

Finally, we did two Focused Principal Component Analysis (FPCA) in order to better understand how the different variables which we considered during the study could explain the *Feeling while driving* and *Driving Style* reported by drivers in the driving behaviour questionnaire. Results confirmed the previous observations and indicated that the first indicator,

DriStyle, was significantly and positively correlated with *SpeedMax* and *VFDyn* and negatively correlated with *TMT*, *RT* and *Age* (Fig.11a). **We could assume then that, the less the participants reported a caution driving style, the higher was their speed on the driving simulator, the higher was the size of their dynamic visual field, the younger they were, the better their mental flexibility score was and the shorter their response time was.** Concerning the *DriFeel* indicator, none of the variables considered were significantly correlated with it (Fig.11b). **This meant that the feeling while driving was not influenced by age, cognitive or visual competencies and did not lead to any behavioural adaptations.**

/Insert Fig.11 about here/

4. Discussion

The aim of this study was to compare young and elderly participants' driving competencies using a driving simulator and allowing to assess at the same time cognitive functions solicited by the driving activity, their behaviour in various situations of driving, their visual field of view in a dynamic and realistic driving situation and their self-assessment about their driving competencies. To do that, we compared young and elderly drivers by using different scenarios on a driving simulator. These scenarios were designed to test drivers in situations that were intended to solicit the visual and cognitive competencies identified as problematic for elderly drivers. Moreover, participants' performance in standard cognitive tests was also considered.

4.1 Cognitive evaluation of elderly participants

In terms of cognitive competencies, we observed that elderly drivers were slower than young drivers to perform a visuomotor task implying a switch between two instructions: in other words, elderly drivers lacked mental flexibility (TMT). This is congruent with earlier studies in which elderly drivers undertook a TMT test (Horswill et al., 2008; Elkin-Frankston et al., 2007). Moreover, after driving on the simulator, the elderly participants, in our study, felt that driving placed them under greater mental and physical demand (as indicated by the result of the NASA TLX mental and physical demand dimensions) than young drivers. Considering the definition of the *mental demand* dimension, this indicates that elderly drivers felt that driving task required more mental and perceptual activity and was more complex to perform. This result can be partly explained by the fact that their visual field of view was reduced when

compared with young drivers (see section 3.2.). The reduction in the size of the visual field of view may lead to a feeling of "difficulty in perceiving" and thus inducing an effort to seek information to compensate for the deficit (whatever it is conscious or unconscious). This observed reduction of the visual field of view is also congruent with the results obtained with the UFOV test in previous studies (Ball et al., 2005; Horswill et al., 2008; Sakai et al., 2015) and indicates that our test of dynamic visual field on the driving simulator allows a differentiation to be made between the two groups of participants. Nevertheless, future studies are needed to compare the two tests more precisely. In particular, it is still to be seen if they are equally correlated with actual (and self-rated) driving skills.

4.2. Cognitive functions and management of critical event

By creating critical events on the driving simulator, our aim was to contrast the deficit of certain cognitive functions and the management of different driving situations involving these cognitive functions. **Concerning reaction time**, results showed that elderly drivers had slower reaction time than young participants. This is congruent with the slowdown in hazard detection observed by Horswill et al., (2008). Moreover, we showed that this was mostly the case when no anticipation was possible (*Sudden Brake Event*) or when the event happened in the periphery of the visual field (*Child event*), which was congruent with the reduction of the size of elderly visual field we could observe in the scenario named *Measurement of the visual field*. Despite no accidents occurred in these conditions, we could see that reaction time was sometimes nearly twice higher for elderly than for young participants. This means that elderly, despite the fact that they were perfectly able to manage sudden event when it could be anticipated, could be dangerous as soon as this event happened in the periphery of the visual field or couldn't be anticipated. In the case of the *Sudden Brake Event*, two solutions could be considered to limit dangerousness of elderly drivers. The first one is to drive slowly, which was not observed in the critical event scenario despite elderly drivers self-reported driving slower than young participants. The second solution is to increase the distance from the vehicle in front when driving in file. Despite elderly also self-reported adopting this behaviour, it was unfortunately impossible to verify it on the driving simulator. In any case, this suggests that elderly should be informed further about the need to adopt these behaviours in order to avoid any accident on the road.

With regard to **anticipation**, events implying this function have been well managed by elderly. It was particularly the case with the bus event, where anticipation allowed to obtain a reaction time not statistically different from the one observed for young participants. This

tended to show that elderly had preserved their ability to anticipate and could sometimes use it to compensate for some deficits.

Concerning **mental flexibility**, they did, however, appear less likely to change their initial plans when a sudden event occurred - i.e. choosing another route so as to avoid roadworks and increase in time trajectory in the *Spatial orientation on road* scenario. This was congruent with the difficulties experienced by elderly drivers in terms of mental flexibility, as measured by the TMT. Nevertheless, although they took more time to complete the *Spatial orientation on road* scenario, they did not make mistakes when choosing which direction to follow. This was probably because, by reducing their speed in this condition, they were able to find enough time to read the signs. Moreover, our instructions about following the map and finding the signs for the restaurant probably helped the elderly participants to be in a good position to follow the correct route, as was also shown to be the case in a study by Lithfous et al. (2014). They showed that providing landmark-based encoding instructions had positive effects on spatial learning and on driving for elderly individuals. Furthermore, spatial representations remained stable over time, with performance maintained even after 15 days. These results suggest that age-related difficulties in spatial navigation may be due to a decline in the ability to find landmarks by themselves, leading to the disruption of spatial encoding. Thus, providing efficient encoding strategies could compensate for these deficits.

4.3. Self-report of habits and attitudes in driving and behaviour on the driving simulator

Concerning drivers' self-report, they feel less confident in their ability to manage events. So, they were obviously less performant in the management of the events implying reaction time, as it was observed concerning the management of the *Child event* during the scenario *management of critical events*. Thus, whilst we cannot affirm that elderly drivers in our study were able to precisely identify the nature of their cognitive difficulties, their self-rating indicates that they have a good feeling of their difficulties on the road. This is congruent with the data obtained by Meng and Siren (2012), who observed that elderly drivers had more a "feeling" than a real awareness of their difficulties. In this sense, our elderly drivers were more conscious of the extent of their difficulties than those involved in a study by Wong et al. (2012). In that study, regardless of cognitive ability, participants thought that they possessed good health and driving abilities. They were confident driving in a range of potentially hazardous situations and they reported similar intentions with regarding their ability to keep on driving.

Elderly claimed to be more cautious, showed higher compliance to road signs and reported fewer offences on the road than young drivers did. This has been confirmed on the

driving simulator as elderly had fewer dangerous behaviours than young participants. Nevertheless, they didn't differ concerning offences observed in the driving simulator. They also reported driving at lower speed but this has been observed in the simulator only in the situations where they needed to slow down in order to find their way. So, on the basis of what has been observed on the driving simulator, the self-report behaviour of elderly people is consistent with their behaviour on the simulator. An interesting point worth highlighting concerns the analysis of the variable composing the *Driving style* indicator. It has been shown that young and elderly participants' answers differed significantly on all the variables except the *Risk* and *CareDri* variables. Exactly as if, when directly questioned on their caution when driving, it was difficult for them to have an objective look on their behaviour, increasing the variability among the answers. So, despite these variables were correlated significantly to the *DriStyle* dimension, they were not enough, considered alone, to make a distinction between the two groups concerning cautious behaviour.

It is also noteworthy that the two groups didn't differ regarding their feeling while driving. Elderly drivers didn't feel more stress or effort than young drivers. Moreover, despite elderly drivers felt less able to manage unexpected events, they didn't feel less able to operate the car.

4.4. Self-regulating behaviour

Self-limitation strategies, highlighted by the elderly participants, seemed consistent with the cognitive difficulties they obviously suffered. So, they self-reported a slower speed and a larger gap between their vehicle and the car in front. Actually, this may help to compensate for executive function faults and increase of reaction time. Speed limitation in the scenario *spatial orientation on the road* is a particularly good example of an adaptive behaviour as a function of task constraint. Thus, the speed limitation was observed only in the situations where the elderly participants needed more time to find their route. Finally, we observed that, on contrary to popular belief, elderly people, in our study, did not limit themselves with respect to the type of road they used. They were prepared to drive in towns, even when they knew it could be difficult at busy times of the day (as they were told before beginning the scenario *spatial orientation on the road*). This was surprising considering their more limited visual field, which may make them feel less confident at managing critical events (as observed in their self-rating scale), more particularly in town. Because of the reduction in the visual field of view, events can sometimes be perceived later. Thus, they are more unexpected and critical to manage.

4.5. Elderly driver's profile

From the analysis of the data obtained in this study, we can say that elderly drivers we considered, could be characterised by : a worse mental flexibility, a higher reaction time when anticipation was impossible or limited, a reduction of the size of the visual field in dynamic conditions, a more cautious self-reported driving style and a smaller number of dangerous behaviours during the management of some critical events on the driving simulator and a slower speed on the driving simulator when they had to look for road signs.

With regard to the dangers associated with elderly drivers' behaviour on the road (as assessed on the driving simulator), they tended to drive slowly and took fewer risks when faced with some critical events. They were not involved in any road accidents, despite they sometimes took longer to react (longer braking time). Nevertheless, considering the high increase of reaction time in some conditions, we couldn't exclude the possibility that elderly could be dangerous in some critical situations (shorter time to react, concurrent task to perform). Thus, Thompson et al. (2012) showed that elderly dangerousness would be mostly observed in situations where elderly drivers have to carry out a concurrent task that impacts on attentional capacities, which was not the case in our study where participants were tested in very favourable conditions. So, we couldn't affirm that no accident would be caused by elderly drivers in our study in less favourable conditions. Nevertheless, we can object that some studies showed elderly drivers tending precisely to limit their engagement in secondary tasks (Charlton et al., 2013). In fact, many studies showed that elderly are able to regulate their behaviour as soon as they are informed about their difficulties. For example, Ross et al. (2009) showed that drivers who were considered as being at-risk for subsequent crashes, based upon UFOV results, regulated their driving more than the lower-risk participants. Nevertheless, despite this self-regulation, a larger sample of these elderly drivers caused at-fault crashes within the two years following the UFOV test compared with the not-at-risk group. However, Oswley et al. (2003) showed that an educational procedure designed to learn how to identify and circumvent difficulties does help to promote safer road behaviour for older people. Other authors have also shown the positive effects of an exercise program on several factors associated with the driving performance of elderly people (Marmeleiraa et al., 2009; Levasseur et al., 2015). For example, Levasseur et al. (2015) showed that when exposed to an awareness tool for safe and responsible driving known as OSCAR (a written document comprising a series of 15 questions and 15 tips linked to aging and driving), the majority of older participants (67-84 years old) confirmed that changes had occurred in at least one of the factors affecting their driving ability. Half of the older drivers reported having started to use six or more compensatory strategies.

5. Conclusion

This study showed that although elderly drivers did not always perform as well as young drivers, they were nevertheless able to make some adjustments. Thus, we can conclude that elderly drivers seemed sufficiently aware of their difficulties to put in place some compensatory strategies. In future work with this population, more should be done in order to strengthen their perception and understanding of driving difficulties and help them in the setting up of coping methods with respect to these difficulties (such as the OSCAR tool developed by Levasseur et al., 2015). Nevertheless, it is noteworthy to keep in mind that this study is an explorative study and as such it suffers from some limitations (like the small number of participants). As a consequence, it implies being very cautious about the generalization of the results obtained. Moreover, the critical events encountered during the driving task - even though it was representative of a large scope of everyday life situations - remain limited when compared to the large variety of situations that could be encountered in real life. Concerning the driving situations in town, the behaviours of the other road users were probably more fair-play than what can be sometimes encountered in real life. In spite of these limitations, these results provide interesting research leads on how driving simulator can be used to create scenarios devoted to the assessment of elderly driving competencies and practices.

References

1. Achkerman, ML., Crowe, M., Vance, DE., Wadley, VG, Owsley, C., & Ball, KK. (2010). The impact of feedback on self-rated driving ability and driving self-regulation among older adults. *The Gerontologist*. Vol. 51(3): 367–378; doi:10.1093/geront/gnq082.
2. Baldock, MRJ., Mathias, JL., McLean, AJ., & Berndt, A. (2006). Self-regulation of driving and its relationship to driving ability among older adults. *Accident Analysis and Prevention*. 38: 1038–1045.
3. Bellanger, A., Gagnon, S., & Yamin, S. (2009). Capturing the serial nature of older drivers' responses towards challenging events: A simulator study. *Accident Analysis and Prevention*. 42(3):809-17.
4. Ball, KK., Clay, OJ., Wadley, VG., Roth, DL., Edwards, JD., & Roenker, DL. (2005). *Predicting Driving Performance in Older Adults with the Useful Field of View Test: A Meta-Analysis*. In: Proceedings of the Third International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design. June 27-30, 2005. Rockport, Maine. Iowa City, IA: Public Policy Center, University of Iowa : 51-57. <https://doi.org/10.17077/drivingassessment.1142>.
5. Cegarra, J., & Morgado, N. (2009) *Étude des propriétés de la version francophone du NASA-TLX*. In: Cahour, B., Anceaux, F., Giboins, A. (Eds.). EPIQUE 2009: 5ème Colloque de Psychologie Ergonomique. Nice, France. pp. 233–239.
6. Charlton, JL., Catchlove, M., Scully, M., Koppel, S., & Newstead, S. (2013). Older driver distraction: A naturalistic study of behaviour at intersections. *Accident Analysis and Prevention*. 58 : 271– 278.
7. Devlin, A., & McGilivray, JA. (2014). Self-regulation of older drivers with cognitive impairment: A systematic review. *Australasian Journal on Ageing*. 33 (2): 74–80; DOI: 10.1111/ajag.12061.
8. Ebnali, M., Ahmadnezhad, P., Shateri, A., Mazloumi, A., Heidari, M.E., & Nazeri, A.R. (2016). The effects of cognitively demanding dual-task driving condition on elderly people's driving performance; Real driving monitoring. *Accident Analysis and Prevention*. 94: 198–206.
9. Elkin-Frankston S, Lebowitz BK, Kapust LB, Hollis AM, & O'Connora MG. (2007). The use of the Color Trails Test in the assessment of driver competence: Preliminary report of a culture-fair instrument. *Archives of Clinical Neuropsychology*; 22:631–635.
10. Esterman B. (1982). Functional scoring of the binocular field. *Ophthalmology* 89:1226-1234.
11. Hart, S.G., & Staveland, L.E., 1988. Development of NASA-TLX (task load index): *results of empirical and theoretical research*. In: Hancock, P.A., Meshkati, N. (Eds.). Human Mental Workload. North Holland Press, Amsterdam. pp. 239–250.
12. Horswill, MS., Anstey, KJ, Hatherly, C., Wood, JM., & Pachana, NA. (2011). Older drivers' insight into their hazard perception ability. *Accident Analysis and Prevention*. 43: 2121– 2127.
13. Horswill, MS., Marrington, SA., McCullough, CM., Wood, J., Pachana, NA., McWilliam, J., & Raikos, MK. (2008). The hazard perception ability of older drivers. *The Journals of Gerontology*. 63B(4): 212-218.
14. Horswill, MS., Pachana, NA., Wood, JM., Marrington, SA., McWilliam, J., & McCullough, CM. (2009). A comparison of the hazard perception ability of matched groups of healthy drivers aged 35 to 55, 65 to 74, and 75 to 84 years. *Journal of the International Neuropsychological Society*. 15: 799 – 802; doi:10.1017/S1355617709990312.
15. Lechner, D., Delanne, Y., Schaefer, G., & Schmitt, V. (1997). *Méthodologie de validation du logiciel de dynamique automobile CALLAS, SIA 970202*. In Congrès SIA Lyon, Avril 1997. Reprinted in Ingénieurs de l'Automobile. No. 713. May 1997.
16. Levasseur, M., Audet, T., Gelinat, I., Bédard, M., Langlais, ME., Therrien, FH, Renaud, J., Coallier, JC., & D'amours, M. (2015). Awareness tool for safe and responsible driving (OSCAR): A potential educational intervention for increasing interest, openness and knowledge about the abilities required and compensatory strategies among older drivers. *Traffic Injury Prevention*. 16:6. 578-586. DOI:10.1080/15389588.2014.994742.

17. Lithfous. S., Dufour. A., Moessinger. M., Bilz. L., Sundby. C., & Després. O. (2014). Appropriate encoding strategies compensate for driving abilities in elderly individuals: a virtual reality study. *Journal of American Geriatrics Society*. 62(9):1795-1797.
18. Marie Dit Asse. L., Fabrigoule. C., Helmer. C., Laumon. B. & Lafont. S. (2014). Automobile Driving in Older Adults: Factors Affecting Driving Restriction in Men and Women. *J Am Geriatr Soc*.62:2071–2078.
19. Marmeleira. JF., Godinho. MB., & Fernandes. OM. (2009). The effects of an exercise program on several abilities associated with driving performance in older adults. *Accident Analysis and Prevention*. 41:90–97.
20. Meng. A., & Siren. A. (2012). Cognitive problems, self-rated changes in driving skills, driving-related discomfort and self-regulation of driving in old drivers. *Accident Analysis and Prevention*. 49: 322– 329.
21. Milleville-Pennel. I., & Charron. C. (2015). Driving for real or on a fixed-base simulator: Is it so different? An explorative study. *Presence*. 24(1). 74-91.
22. Milleville-Pennel. I., Mars. F., Zanlonghi. X., Rozière. T. & Barrucand. A. (2018). Ecological method to assess visual field deficit while driving. *20th Congress International Ergonomics Association*. August. Florence. Italia.
23. Oswley. C., Stalvey. BT., & Phillips. JM. (2003). The efficacy of an educational intervention in promoting self-regulation among high-risk older drivers. *Accident Analysis and Prevention*. 35: 393–400.
24. Papa.M., Boccardi. V., Prestano. R., Angellotti. E., Desiderio. M., Marano. L., Rizzo. MR., & Paolisso. G. (2014). Comorbidities and crash involvement among younger and older drivers. *PLoS One*. April 2014. vol9 (4). e94564.
25. Rakotonirainy. A., Steinhardt. D., Delhomme. P., Darvell. M., & Schramm. A. (2012). Older drivers' crashes in Queensland, Australia. *Accident Analysis and Prevention*. 48: 423-429.
26. Reimer. B., Donmez. B., Lavallière. M., Mehler. B., Coughlin. J.F., & Teasdale. N. (2013). Impact of age and cognitive demand on lane choice and changing under actual highway conditions. *Accident Analysis and Prevention*. 52: 125– 132.
27. Rimmo. PA., & Hakamies-Blomqvist. L. (2002). Older drivers' aberrant driving behaviour, impaired activity, and health as reasons for self-imposed driving limitations. *Transportation Research Part F*. 5: 47–62
28. Ross. L.A., Clay. O.J., Edwards. J.D., Ball. K.K., Wadley. V.G., Vance. D.E., Cissell. G.M., Roenker. D.L., & Joyce. J.J. (2009). Do older drivers at-risk for crashes modify their driving over time? *Journal of Gerontology: Psychological Sciences*. 64B(2):163–170. doi:10.1093/geronb/gbn034.
29. Sakai. H., Uchiyama. Y., Takahara. M., Doi. S., Kubota. F., Yoshimura. T., Tachibana. A. & Kurahashi. T. (2015). Is the useful field of view a good predictor of at-fault crash risk in elderly Japanese drivers? *Geriatr Gerontol Int*. 15: 659–665; doi: 10.1111/ggi.12328.
30. Spreen O. & Strauss E. (1998). *A compendium of neuropsychological tests: Administration, norms and commentary*. 2nd ed. New York: Oxford University Press.
31. Tombaugh TN. Trail Making Test A and B: Normative data stratified by age and education. *Archives of Clinical Neuropsychology* 2004;19:203–214.
32. Thompson. KR., Johnson. AM., Emerson. JL., Dawson. J.D., Boer. ER., & Rizzo. M. (2012). Distracted Driving in Elderly and Middle-Aged Drivers. *Accid Anal Prev*. 45(2): 711–717. doi:10.1016/j.aap.2011.09.040.
33. Wetton. M.A., Horswill. M.S., Hatherly. C., Wood. J., Pachana. N.A., Anstey. & K.J. (2010). The development and validation of two complementary measures of drivers' hazard perception ability. *Accident Analysis and Prevention* 42 (4). 1232–1239.
34. Wang CC, Kosinski CJ, Schwartzberg JG, & Shanklin AV. (2003). *Physician's guide to assessing and counseling older drivers*. Washington, DC: National Highway Traffic Safety Administration.
35. Wong. IY., Smith. S.S., & Sullivan. K. (2012). The relationship between cognitive ability, insight and self-regulatory behaviours: Findings from the older driver population. *Accident Analysis and Prevention*. 49: 316– 321.

36. Yee. WY.. Cameron. PA. & Bailey. MJ. (2006). Road traffic injuries in the elderly. *Emerg Med J.* 23: 42–46. doi: 10.1136/emj.2005.023754.
37. Zanlonghi. X.. Bizeau . T.. Mars. F.. Boisliveau. R. & Milleville-Pennel. I (2017). Neuropathie optique et conduite : mise en évidence de comportements de compensation visuelle. *123e Congrès de la Société Française d'Ophtalmologie.* Paris. France.

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Figures caption

Figure 1: Driving simulator

Figure 2: a) static and b) dynamic visual field on the driving simulator.

Figure 3: Four itineraries could be followed by the participants: town or countryside, roadworks or diversion.

Figure 4: a) Map of the Scenario *management of critical event*: Child event (zone1), Wheelchair event (zone2), Bus event (zone3), Motorcycle event (zone4), Turn left event (zone5), Sudden brake event (zone6). b) Critical events on the driving simulator: 1) Child event, 2) Wheelchair event, 3) Bus event, 4) Motorcycle event, 5) Turn left event and 6) Sudden brake event.

Figure 5: Mean self-rated workload for each sub-scale of the NASA-TLX. Error bars corresponding to the standard error.

Figure 6: Performance on TMT A and B as a function of 11 age groups and 2 education levels. Age group 18–24 contained only university students with educational levels of 12+ years. According to Tombaugh (2003).

Figure 7: Visual areas involved in the test of visual field. Each circle determines a visual zone that corresponds to the areas covering the whole visual field. The red rectangle delineates the areas of the visual field actually tested on the driving simulator.

Figure 8: Correlations circle of the PCA carried out with the following 16 variables and 30 observations for each variable: *Speed in Town*, *Speed on Highway*, *Acceleration*, *Distance from the vehicle in front*, *Enjoyment in taking risk behind the wheel*, *Forcing lane change*, *Relative Speed with respect to the other drivers*, *Offence reported on the road*, *Careful Driver*, *Compliance to Road Signs*, *Compliance to Weather*, *Pleasure while driving*, *feeling of event mastery*, *feeling of driving task mastery*, *Stress and Effort*.

Figure 9: a) Circle of the correlations of the PCA integrating the variable Age. 15 variables: *Age*, *Speed in Town*, *Speed on Highway*, *Acceleration*, *Distance from the vehicle in front*, *Enjoyment in taking risk behind the wheel*, *Relative Speed with respect to the other drivers*, *Offence reported on the road*, *Careful Driver*, *Compliance to Road Signs*, *Compliance to Weather*, *feeling of event mastery*, *feeling of driving task mastery*, *Stress and Effort*. 30 observations for each variable. b) Position of the *Feeling while driving* and *Driving style* indicators on the two principal dimensions identified in the PCA. These variables were considered as additional variables during the PCA.

Figure 10: a) Circle of the correlations of the PCA with 10 variables: *Age*, *DriStyle*, *DriFeel*, *TMT*, *NasaTLX*, *VFStat*, *VFDyn*, *SpeedMaxRO*, *SpeedMaxCE*, *RT* b) Correlation graph of the PCA with 10 variables (the colour code is explained on scale on the right part of the figure).

Figure 11: a) FPCA with *DriFeel* as explained variable. b) FPCA with *DriStyle* as explained variable.

Table 1. Some examples of self-regulating behaviours as a function of the cognitive ability impacted by cognitive decline.

Cognitive functions impacted by cognitive decline	Self-regulating Behaviours
Anticipation, visual perception	<p><i>Avoiding behaviour:</i> → avoiding driving in the leftmost lane. → reduction of: lane change, driving at night, driving during bad weather, driving in rush hour traffic, driving in unfamiliar areas, or making left turns across oncoming traffic.</p> <p><i>Compensatory strategies:</i> mean speed reduction, increase of the safety distance.</p>
Divided attention	<p><i>Avoiding behaviour:</i> reduction of engagement in secondary tasks.</p> <p><i>Compensatory strategies:</i> when engaged in a secondary task → mean speed reduction, reduction in overtaking activities and reduction of the duration of driving in the unsafe-zone</p>

Table 2. Overview of the tools used and the main analysis conducted to assess driver's self-assessment, cognitive performance and driving performance on the simulator.

Tool	Description	What is assessed	Measurement and analysis conducted	Main results	
Questionnaire on driving behaviour	Part A:	Factual information, driving experience	Answer/value on the scales for each question, <i>t-test</i>	Except concerning driving experience, the two groups have the same driving practice.	
	Part B:	Driving behaviour self-assessment	Value on the scales for each question, <i>PCA</i> , <i>FPCA</i> , <i>t-test</i>	Elderly decreased speed, did less abrupt acceleration, increased the distance to the vehicle in front, enjoyed less taking risks, decreased their speed compared to other vehicles, did fewer infractions, were more cautious, had a lower appreciation of their driving and less sense of control over what is happening on the road, adapted their driving more to driving conditions	
TMT A/B	Part A Part B	Speed of visual and motor processing Mental flexibility	Task duration <i>t-test</i>	Elderly drivers were more affected by the constraints to switching between the two tasks than young drivers.	
Nasa TLX	Cognitive workload	6 dimensions of cognitive workload	Rating on the six dimensions <i>t-test</i>	Mental and physical demand was higher for the elderly than for the young participants.	
Driving simulator	<i>Scenario 1:</i> Introduction				
	<i>Scenario 2:</i> Visual field	Size of the visual field	Number of visual cues detected in the 7 areas of the visual field, <i>t-test</i>	Only the peripheral region of the visual field was impacted by the driving task and this impairment was higher for elderly.	
	<i>Scenario 3:</i> Spatial orientation on the road	Spatial orientation on the road		Number of errors during route tracking, <i>t-test</i>	No group of drivers made errors.
		Mental flexibility		Modification of the initial itinerary, <i>Khi2</i>	Elderly showed a less flexible behaviour.
		Self-regulating behaviour: <i>Avoidance of complex situations</i> <i>Speed reduction</i>	Choice of the king of road, <i>Khi2</i> Speed, <i>t-test</i>	No difference between the two groups. Elderly drivers needed more time to read signs and orient themselves on the road.	
	<i>Scenario 4:</i> Management of critical events	Processing speed: <i>Sudden brake event</i> Processing speed and anticipation: <i>Bus event</i> <i>Child event</i>	Reaction time, number of accidents <i>t-test</i> , <i>Khi2</i>	Longer reaction time for elderly participants.	
		Anticipation and visual exploration: <i>Motorcycle event</i> Compliance with driving and safety rules: <i>Turn left event</i> and <i>wheelchair event</i>	Number of accidents, number of risky behaviours <i>Khi2</i>	Elderly drivers had fewer dangerous behaviours than young participants. None of the participants were involved in an accident on the driving simulator.	
Self-regulating behaviour: <i>speed reduction</i>		Speed, <i>t-test</i>	No difference between the two groups.		
Global Overview of the data	Relation between Age and some of the previous variables considered	<i>PCA</i>	The less the participants reported a caution driving style, the higher their speed on the driving simulator was, the higher the size of their dynamic visual field was, the younger they were, the better their mental flexibility was and the shorter their response time was.		

Table 3. Items proposed in the part B of the questionnaire on driving behaviour. This is an approximate translation of the French version of the questionnaire which aims at giving a general idea of the content and that could not be used as such. The validation of the questionnaire has been performed on the French version of the questions. The scale used to answer was always a continuous straight line of 10 cm length quoted from 0 to 100. The variables used for the statistical analysis and the computation for the two indicators (see section 3.4) are indicated in bold characters.

Variables names	Questions	Quotation
Speed in Town (SpeedTo)	"How fast can you drive in the city?"	Value indicated by the participant (km/h)
<i>Speed on National Road</i>	"How fast can you drive on National Road"	Value indicated by the participant (km/h
<i>Speed on Express way</i>	"How fast can you drive on Expressway"	Value indicated by the participant (km/h
Speed on Highway (SpeedHi)	"How fast can you drive on highway?"	Value indicated by the participant (km/h)
Accélération (Acceleration)	"You prefer when accelerations are?"	Regular and light _____ brisk and intense
Distance from the vehicle in front (DistVeh)	"When driving in line, how far do you tend to keep from the vehicle in front of you?"	High distance _____ Low distance
Enjoyment in taking risk behind the wheel (Risk)	"Do you enjoy taking risks when driving?"	Not at all _____ Yes
<i>Forcing lane change (ForcingLC)</i>	"In general, when you are on an access ramp to an expressway, you try to "force" your insertion"	Never _____ Often
Relative Speed with respect to the other drivers (RelSpeed)	"In general, compared to other drivers, you drive"	Slower _____ Faster
Offences reported on the road (Offence)	"Are you committing traffic violations?"	Never _____ Often
<i>Feeling of being at the mercy of events</i>	"During the driving activity, you have the feeling to"	Be at the mercy of the _____ Not to imponderables _____ be at the mercy of the imponderables
Feeling of event mastery (Emastery)	"During the driving activity, you have the feeling to"	Not control _____ Control what happens _____ what happens
Careful Driver (CareDri)	"In general, you are a driver"	Unwise _____ Very careful
Compliance to RoadSign (RoadSignCom)	"Do you commit traffic violations?"	Never _____ Often
Compliance to Weather (WeatherCom)	"Do you adapt your driving to the weather conditions"	Never _____ Often
Stress (Stress)	"In general, are you stressed while driving?"	Often _____ Never
Effort (Effort)	"How much effort does your driving cost you?"	A great effort _____ No effort
Feeling of driving task mastery (Dmastery)	"How would you rate your overall mastery of driving activity"	Bad mastery _____ Good mastery
<i>Pleasure while driving (Pleasure)</i>	"For you, is driving an activity?"	Very unpleasant _____ Very pleasant

Table 4. Description of the two principal dimensions of the PCA about the part B of the driving behaviour questionnaire.

Dimension 1			Dimension 2		
Variables	Correlation	p-value	Variables	Correlation	p-value
RelSpeed	0.81	7.20E-08	DMastery	0.81	5.91E-08
Offence	0.80	1.01E-07	Effort	0.77	6.68E-07
SpeedHi	0.79	1.70E-07	Stress	0.73	4.47E-06
SpeedTo	0.67	4.60E-05	EMastery	0.36	4.96E-02
Acceleration	0.67	4.80E-05			
DistVeh	0.65	8.90E-05			
Risk	0.62	2.72E-04			
EMastery	0.48	7.23E-03			
WeatherCom	-0.52	3.25E-03			
CareDri	-0.54	2.02E-03			
RoadSignCom	-0.74	3.36E-06			

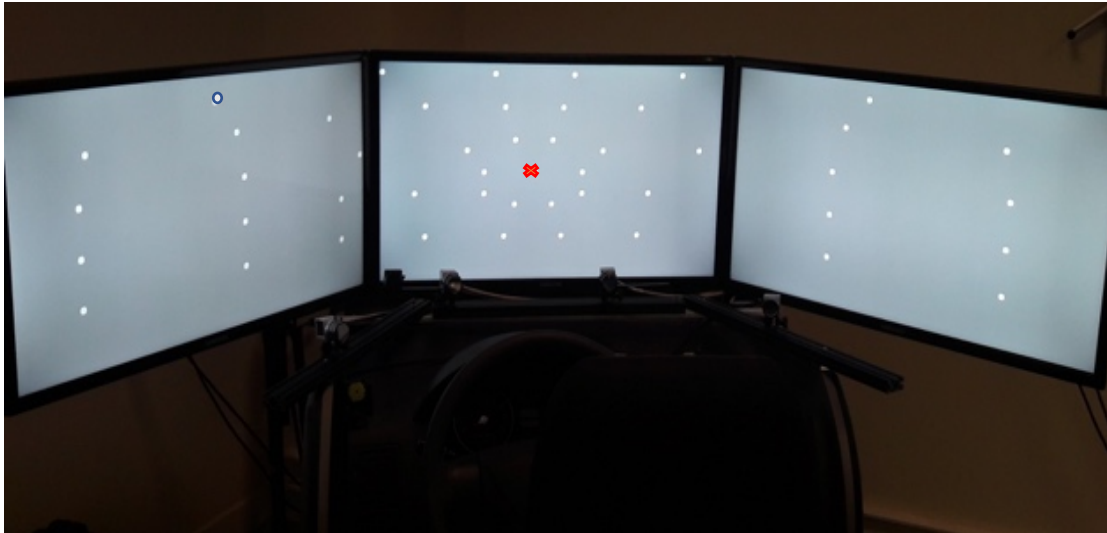
Table 5. T-test and p-value of the comparisons between Young and Elderly drivers for each variable considered in the driving behaviour questionnaire.

<i>Variables</i>	<i>Mean Young</i>	<i>StandardError</i>	<i>Mean Elderly</i>	<i>StandardError</i>	<i>T-Test (ddl=28)</i>	<i>P value</i>
<i>Driving Style</i>	50,52	10,37	35,46	9,33	4,31	0.00
SpeedTo	63.61	10.54	51.67	8.35	3.56	0.00
SpeedHi	137.89	9.50	125.00	9.29	3.93	0.00
Acceleration	41.11	26.61	26.67	16.79	2.02	0.05
DistVeh	42.44	19.86	29.92	18.50	2.08	0.05
Risk	19.89	21.62	13.92	22.22	1.21	0.23
RelSpeed	55.11	15.92	36.67	17.80	3.24	0.00
Offence	34.11	20.53	15.75	13.11	3.02	0.01
EMastery	67.61	17.72	48.33	26.68	2.69	0.01
CareDri	67.83	17.21	78.42	20.45	1.89	0.07
RoadSignCom	73.39	16.34	90.42	10.08	3.48	0.00
WeatherCom	64.83	18.65	89.00	9.89	4.36	0.00
<i>Feeling while driving</i>	73,17	17,21	79,00	16,01	1.38	0,18
Stress	73.28	22.16	81.83	19.63	1.50	0.14
Effort	75.94	19.06	80.67	25.13	1.10	0.28
DMastery	70.28	19.34	74.50	16.81	1.12	0.27



Figure 1

a)



b)

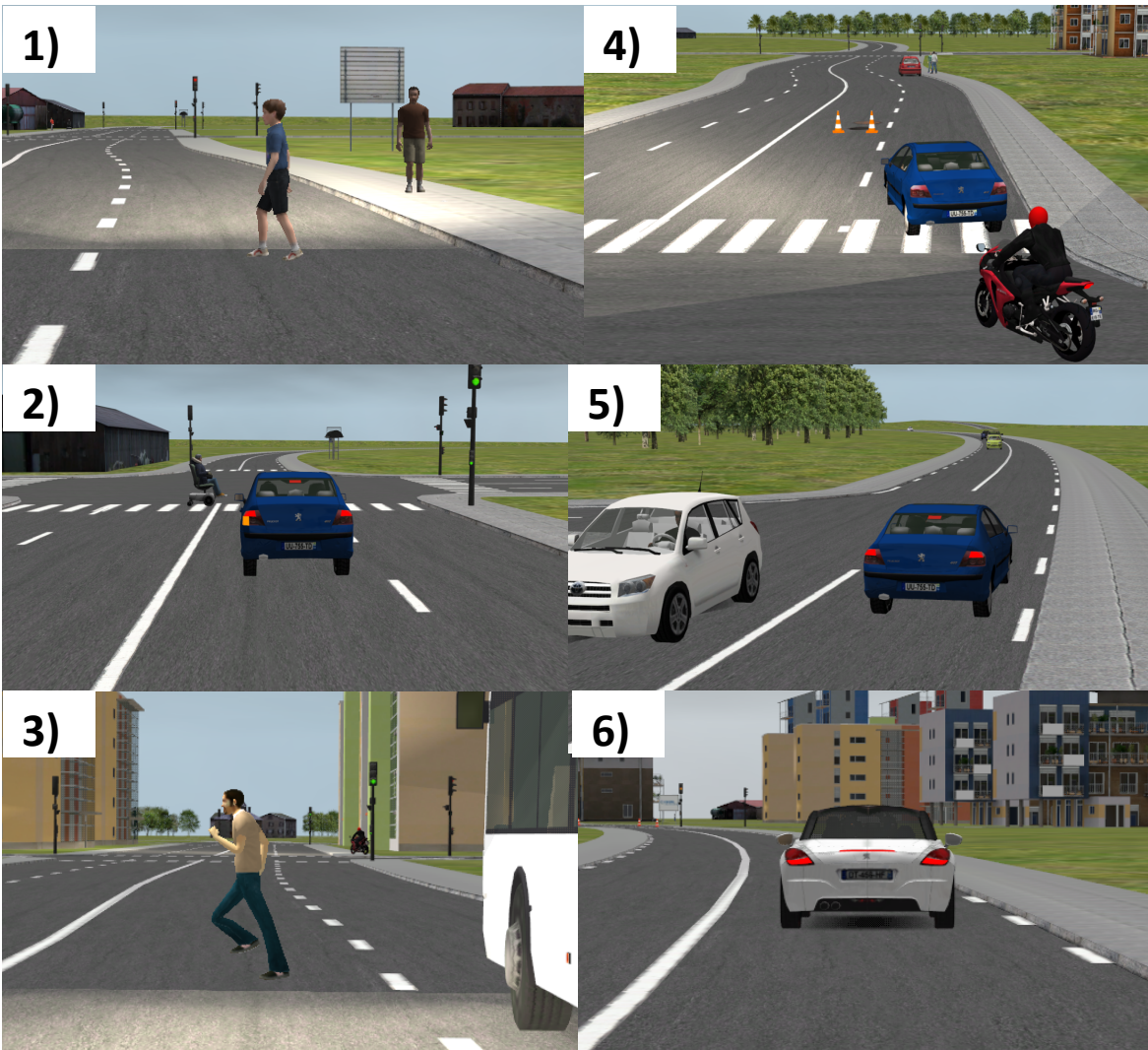


Figure2



Figure3

a)



b)



Figure 4

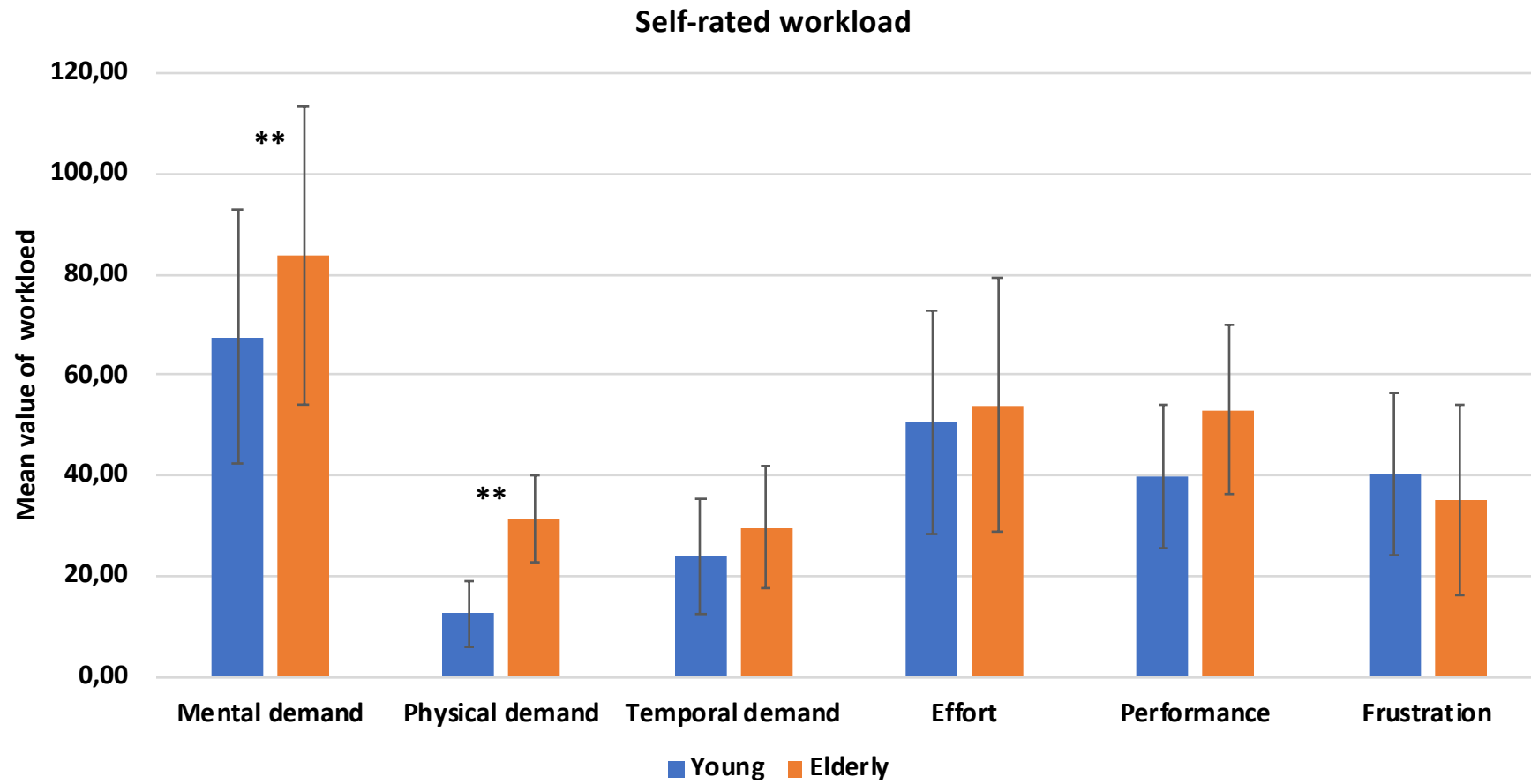


Figure5

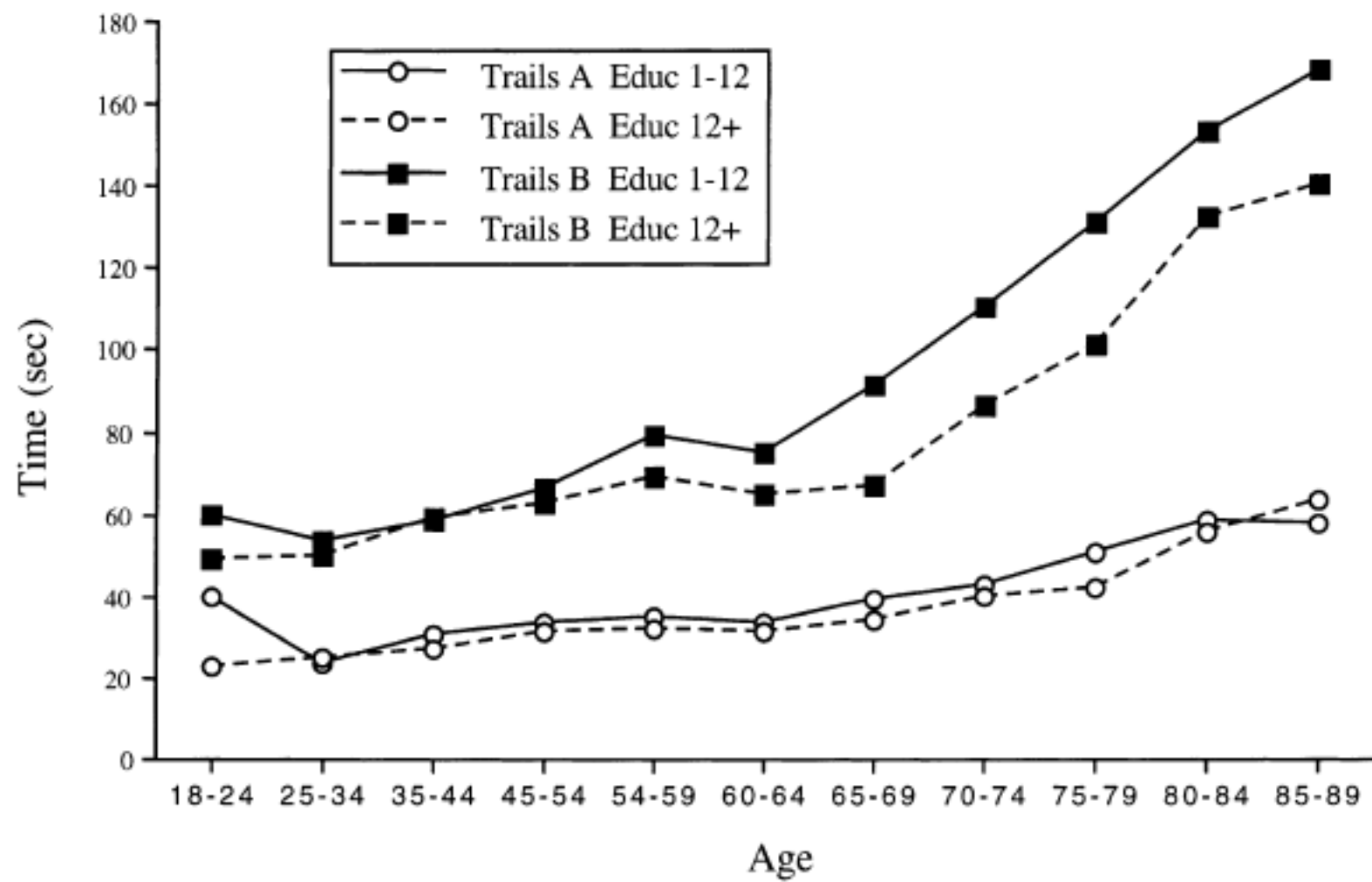


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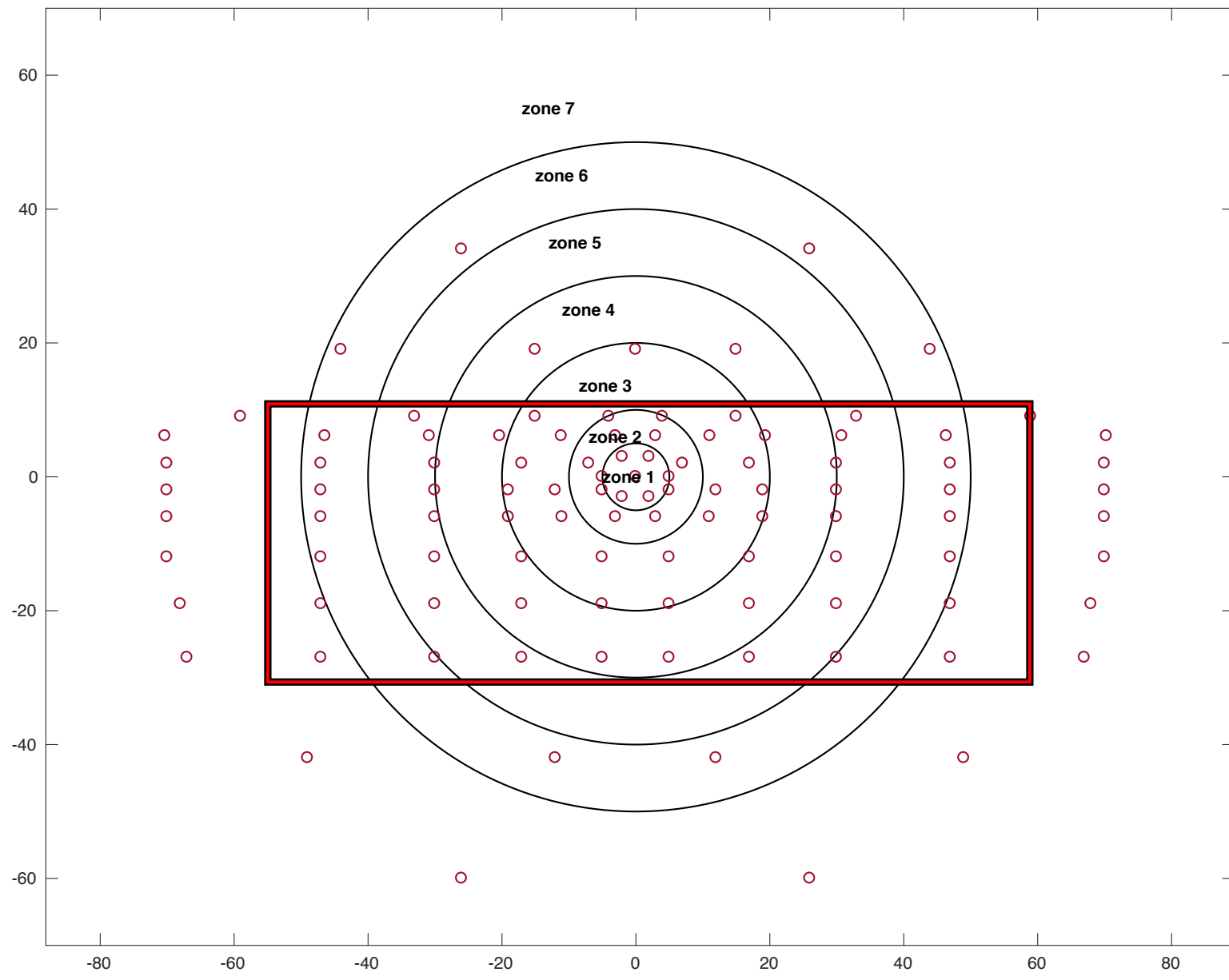


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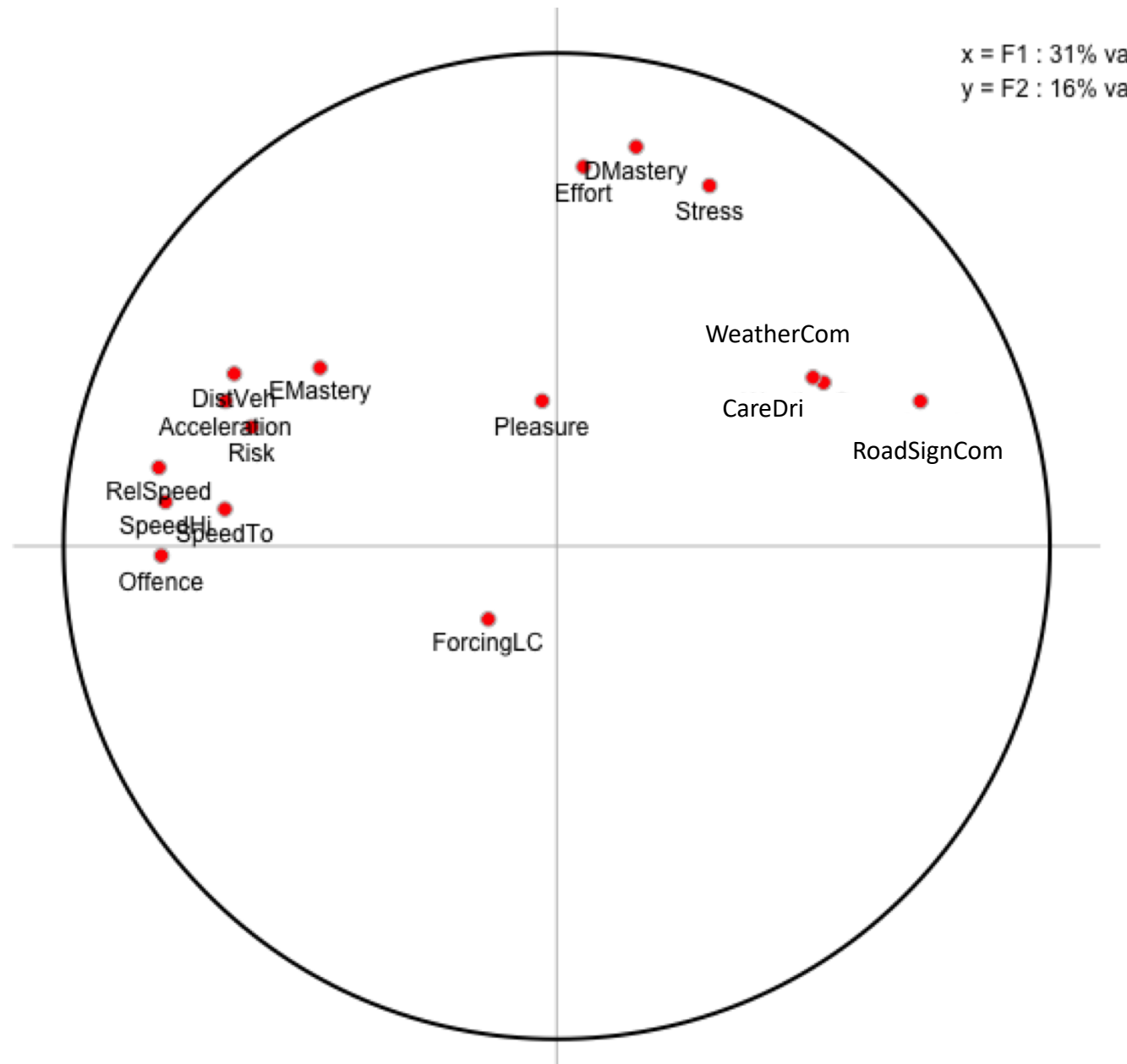
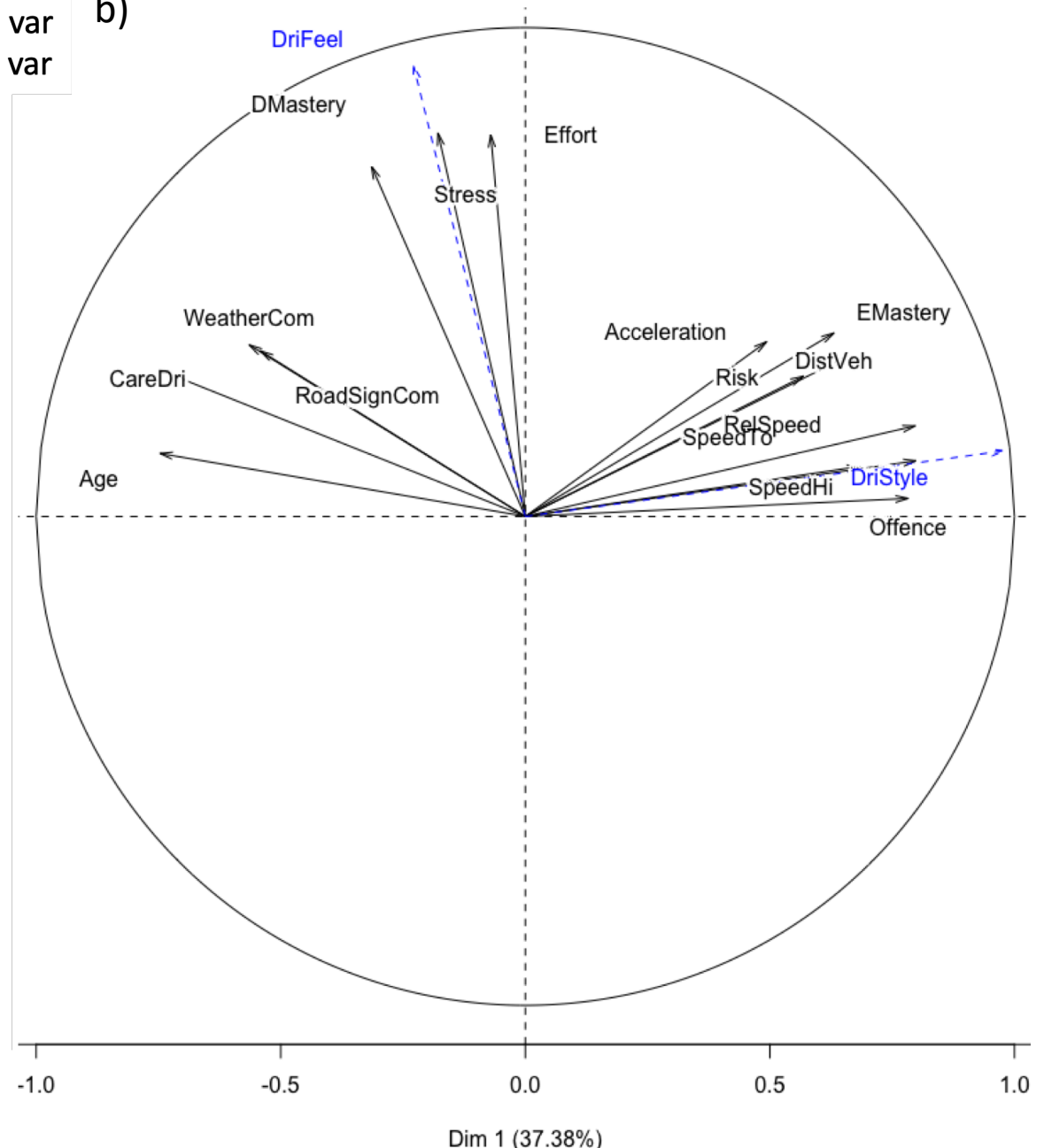
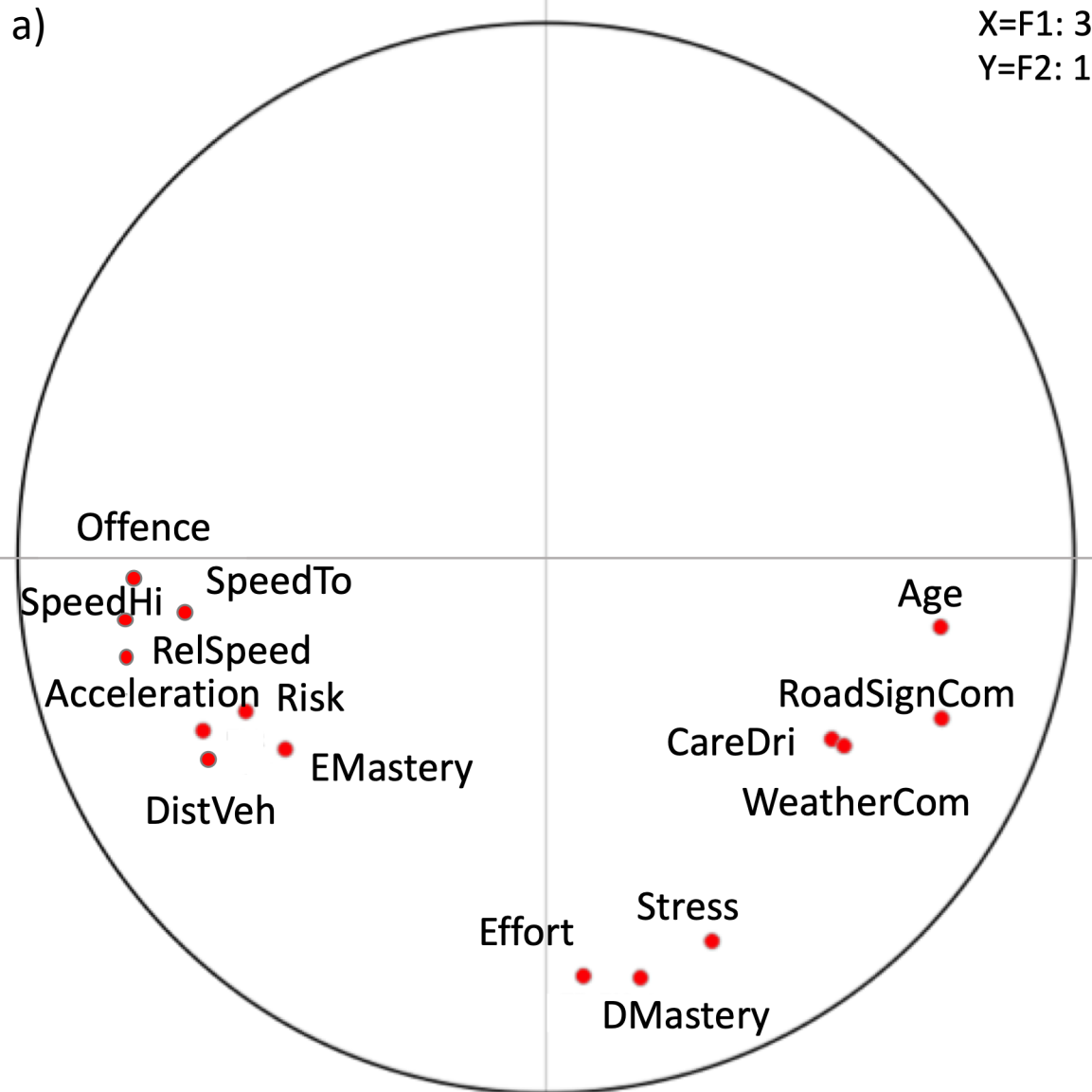
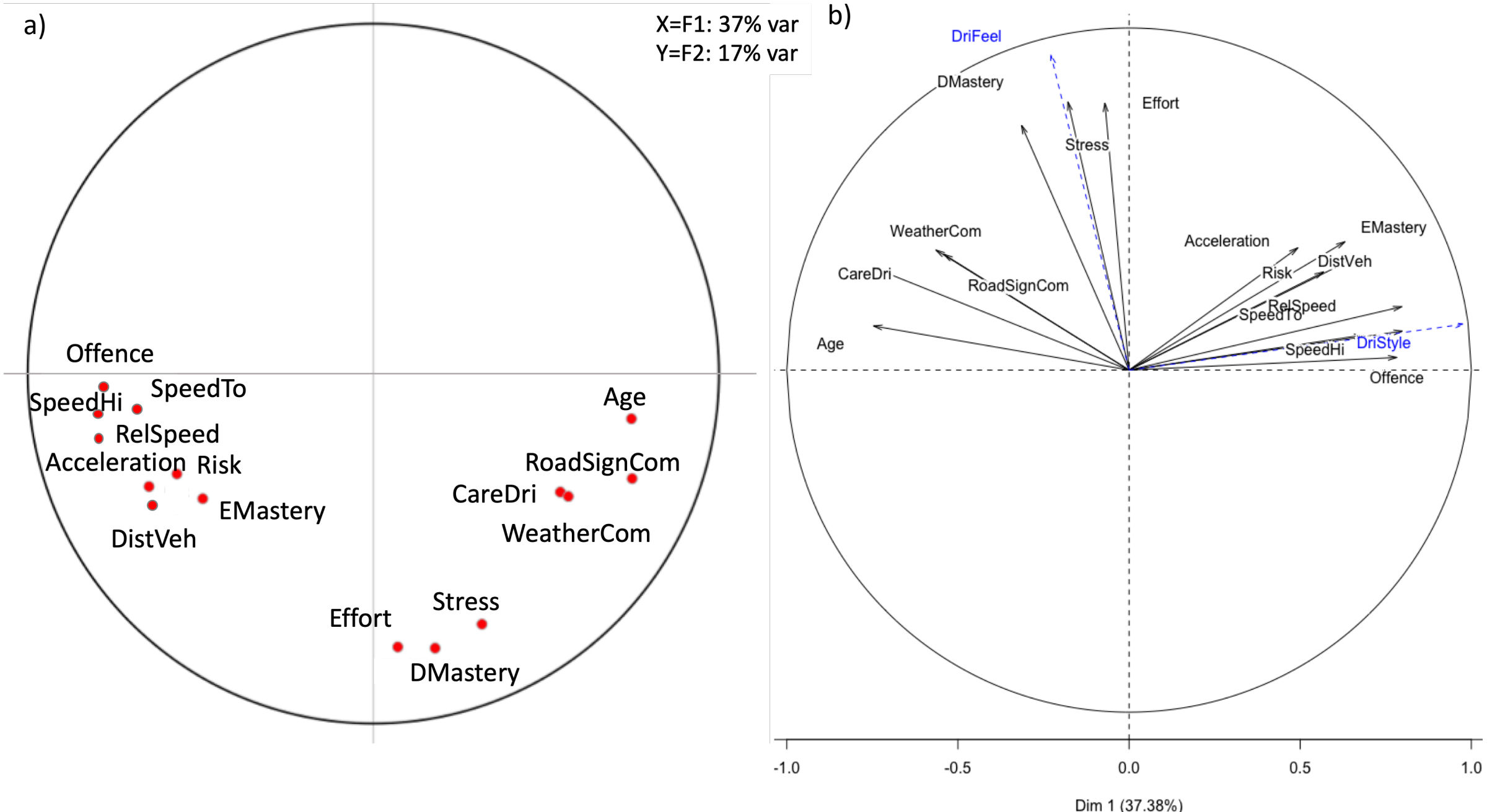


Figure 8



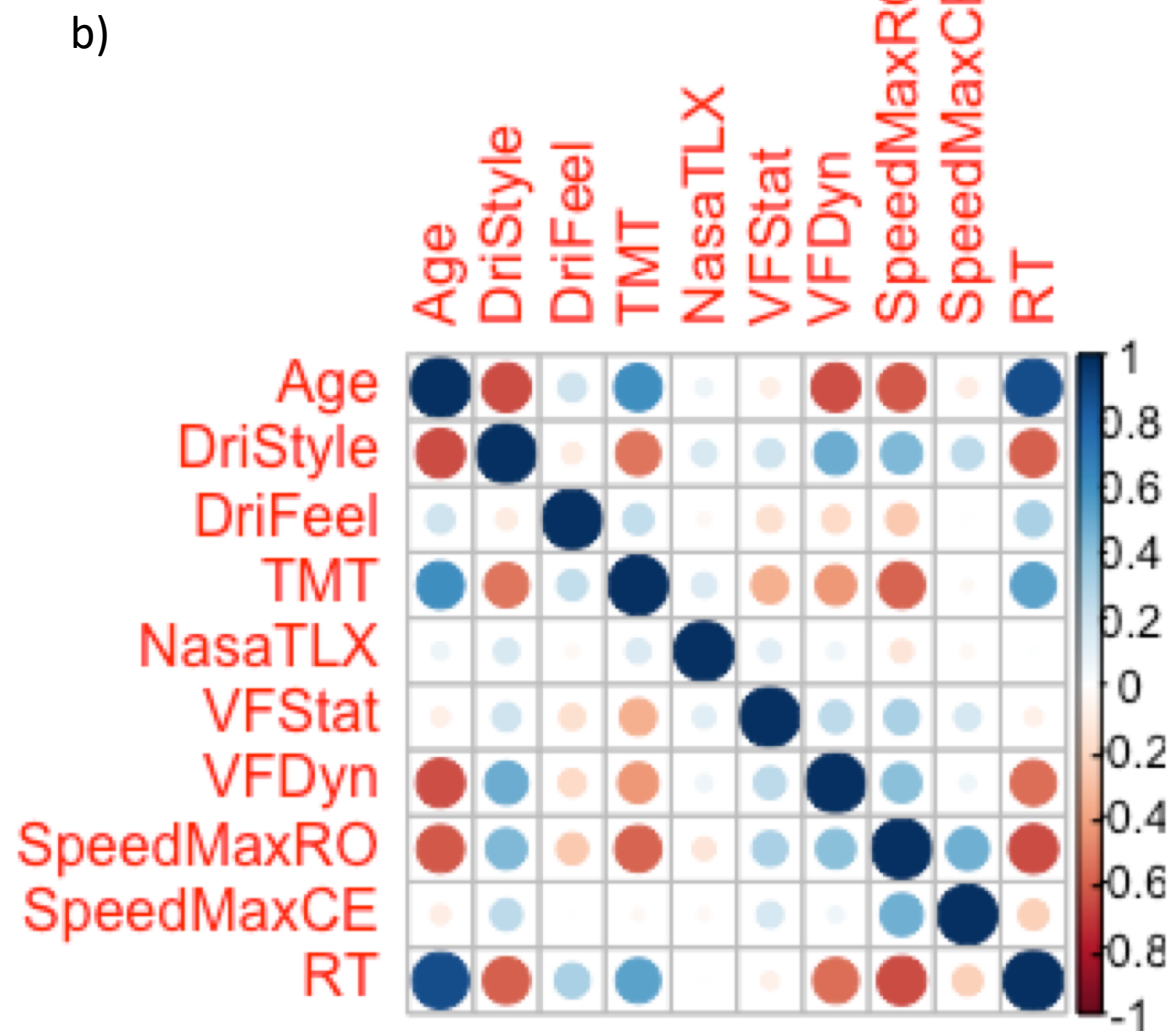
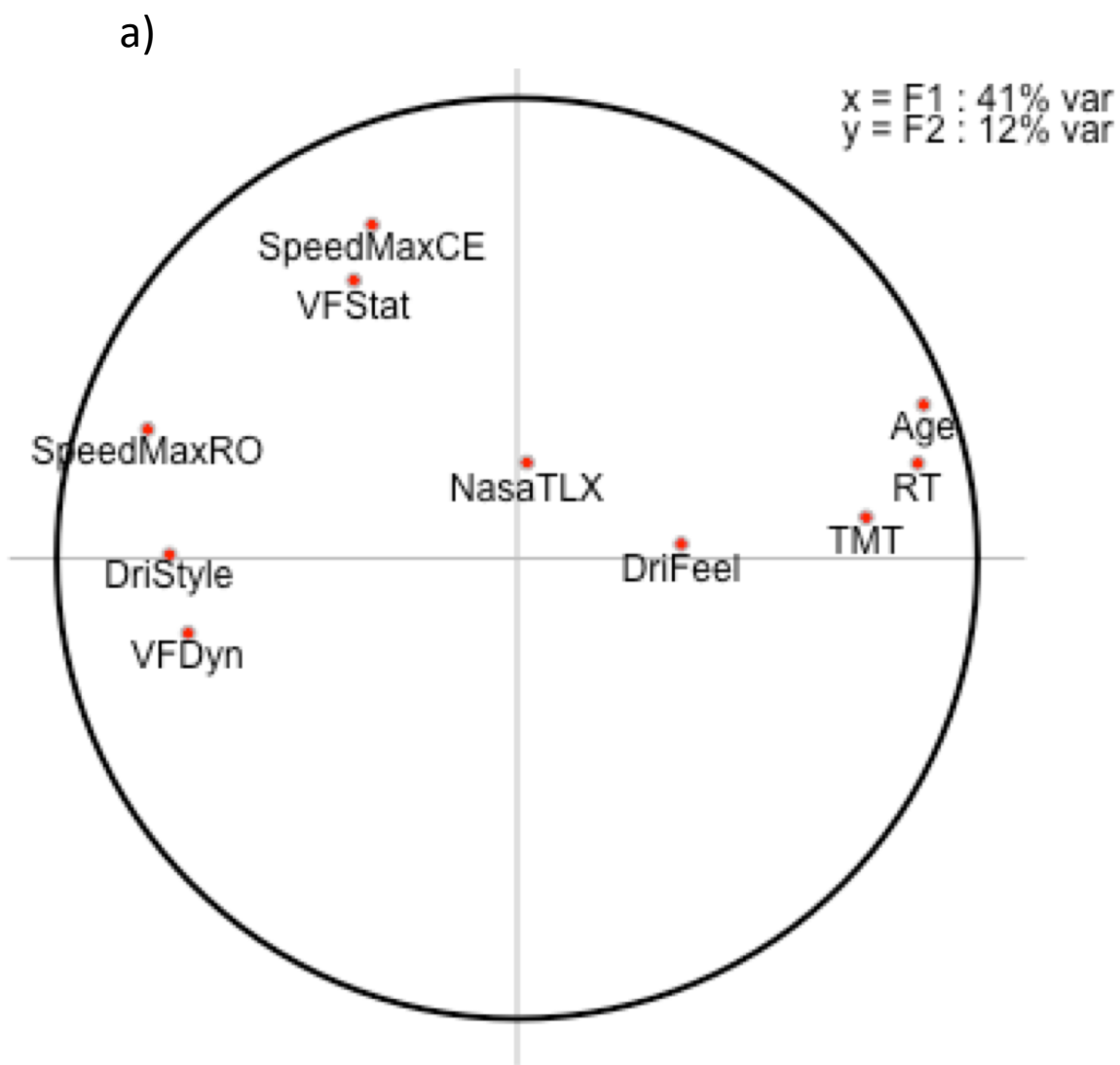


Figure 10

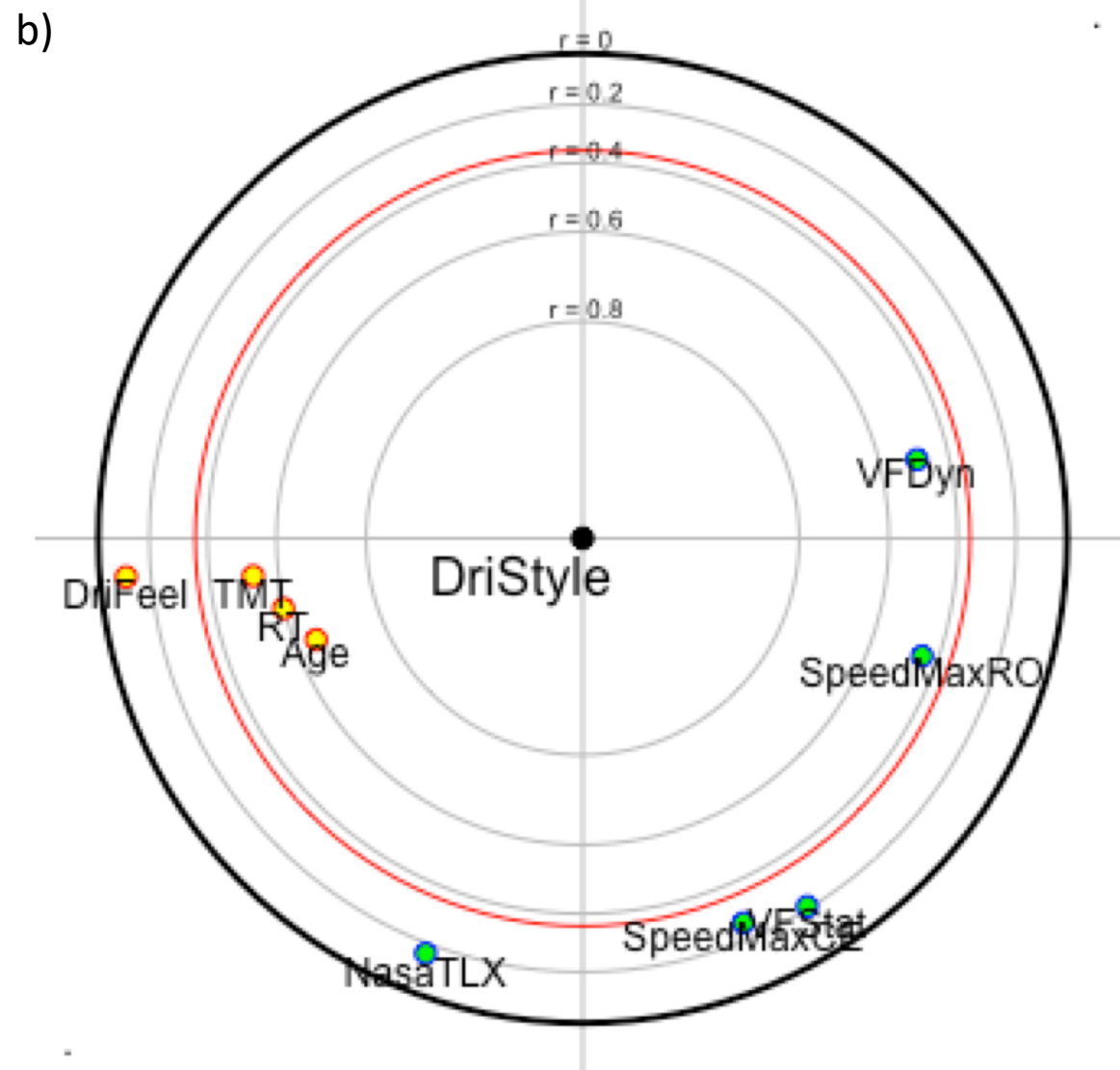
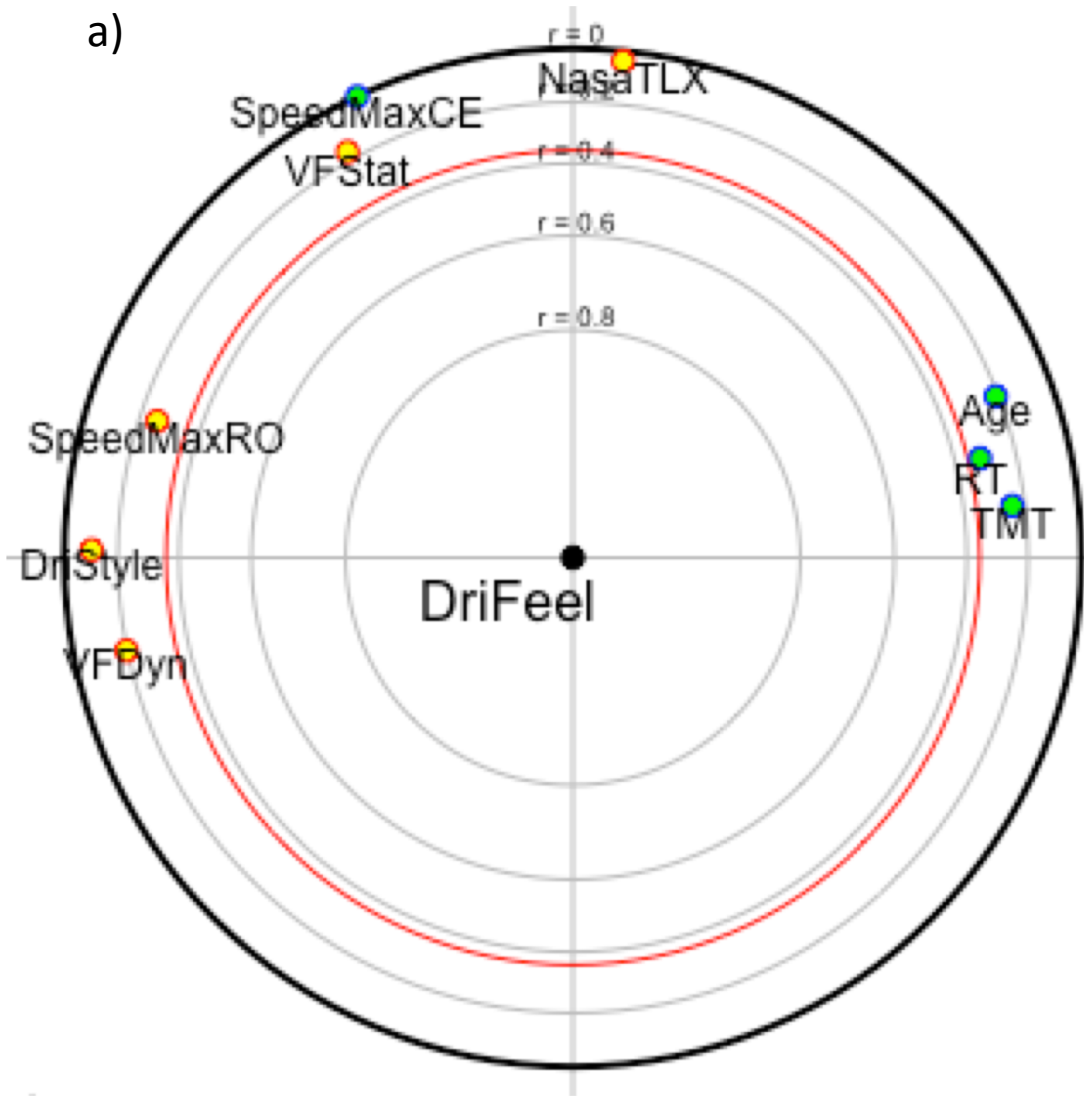


Figure 11