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Mental flexibility impairment in drivers with early Alzheimer's disease: A simulator-based study

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ABSTRACT

After memory impairment, one of the most common troubles of early Alzheimer's disease (AD) is the impairment of executive functioning. However, it can have major consequences on daily life, notably on the driving activity. The present study focused on one important executive function involved in driving: mental flexibility; and considered how this impairment can affect driving. Ten patients with early AD were matched with 29 healthy older drivers. All participants were given an evaluation of mental flexibility through neuropsychological tests and an experimental test developed on a static driving simulator. The experiment was divided in two conditions; one without mental flexibility and another condition with a mental flexibility demand. AD patients showed impairments in the neuropsychological tests evaluating mental flexibility. These deficits are linked to the deficits they showed in the driving simulator flexibility tests. This study contributes to the understanding of mental flexibility mechanisms and on their role in driving activity. It also confirms that the driving simulator is a suitable tool to explore cognitive disorders and driving ability.

1. Introduction

Cognitive functions, as well as perceptual functions, are fundamental to driving. Driving is a complex task and relies strongly on intact cognitive abilities, including the ability to monitor and attend to the road environment, anticipate hazards and respond accurately and quickly to relevant information. This everyday activity requires many different cognitive processes, of which some are automatic but it also requires from the driver a large panel of high level cognitive functions, and it involves the executive system, especially the mental flexibility [1,2]. Older drivers are known to be at higher risk than all other age groups for motor vehicle accidents on a per-mile basis [3,4], and older individuals with early dementia crash risk are two to five times than that of unimpaired older drivers [5]. Moreover, neuropsychological studies on fitness to drive of older drivers and/or impaired drivers have for the most part neglected or limited the assessment of executive functioning.

Executive functions (EF) are very high-level abilities. They allow individuals to anticipate and adapt their behavior to changing situations, and to new situations. For example, attentional control, planning, organization, and mental flexibility, are executive functions [6]. Miyake et al. [7] suggested that the executive system is a global system divided in three components and three main executive functions, — inhibition of automatic responses, updating the content of working memory, and mental flexibility. In the present research, we focused on the mental flexibility component, which seems to be very important component to drive safely [8]. It refers to the ability to switch between cognitive tasks or mental sets [9]. It is an intentional disengagement process of the attention from a situation or a strategy which is not relevant anymore and an engagement towards a new and more adapted situation/strategy. It is sometimes called "mental shifting", "attention switching" or "mental flexibility" [7]. However, some authors prefer to distinguish these concepts [10]. Indeed, it seems that the "mental shifting" refers to the shift of visual attention from one location to another (Posner's paradigm [11]) [12], whereas the "mental flexibility" refers to the concept of displacement towards another pattern of answer (like in the WCST [13,14]) or towards another mental set [10]. In the present study, we refer to this second concept.

Alzheimer's disease (AD) is the most common cause of abnormal cognitive decline in older adults. AD is firstly characterized by deficits in declarative memory, but also by a variety of impairments in high level cognitive abilities. It progressively affects cognitive functions like attention, judgment, reasoning [15], and principally, executive functioning [16]. In the early stages of the dementia, patients are not aware of their

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deficits and continue their daily life as if they were not impaired at all [17]. It is estimated that around one-third of drivers with dementia continue to drive [18]. While healthy older drivers are able to adopt self-regulatory driving behaviors [19], it seems that AD patients, because of anosognosia, could not adopt safe behaviors like avoiding high traffic situations or driving at night. Carr [20] explained in a literature review that the studies on crash risk in drivers with dementia are limited in terms of conclusions because of the small number of participants, the use of self-assessment questionnaires, and by the lack of matched controls participants. However, all the studies surveyed by Carr showed an increase in the number of accidents among drivers with Alzheimer's disease. Another study also showed that drivers with AD, even in the early stages of the disease are at a greater risk of crashes compared to cognitively preserved drivers at the same age [21]. The studies including an neuropsychological assessment and an evaluation of the fitness to drive tend show that the executive functions' impairment are the most correlated with the impairments in driving [8,22].

The literature concerning the impairment of the mental flexibility in AD is quite important. Perry, Watson and Hodges [23], Siri et al. [24] and also Souchay, Isingrini and Gil [25] reported impairment in mental flexibility in the early stages of dementia. However, its impairment could have major consequences in daily life, notably on the driving activity [26]. Some studies have also reported that mental flexibility is one of the two major features of attention which seems to be particularly impaired in AD, with the inhibitory mechanisms [10]. Inhibitory and mental flexibility mechanisms are often associated in the literature on executive functioning. However, several studies showed that these two features of executive functions were not completely linked. Miyake et al. showed that they are linked but independent in their functioning and Collette et al. [27] showed that the neural substrates of these functions were different. The present study focused on mental flexibility because the literature is not as abundant as for inhibition.

Daigneault, Joly, and Frigon [1] suggest that executive abilities are important determinants of driving ability among older drivers. Indeed, they showed that older drivers with a history of accidents present impairments on several executive tests compared to participants who do not crash.

A recent review article [28] reported that in the last decade at least sixty-nine articles had been published on the role of executive functions in driving. However, the literature concerning the link between executive disorders in AD and driving is finally not very abundant compared to available studies on the others cognitive impairments, like attention, spatial orientation, etc. [8,29]. However the executive functions are quite impaired in AD and particularly in the early stages of the dementia. The difficulty of showing correlation between neuropsychological evaluation and driving evaluation could be explained by the fact that executive functioning, and more particularly mental flexibility, are not sufficiently taken into account in the studies. Indeed, depending on the driving's characteristics and on the fact that it involves a lot of different cognitive processes, neuropsychological tests that are very focused on only one cognitive function cannot show correlations; hence the importance to include executive functioning evaluations that introduce the concept of cognitive control.

The main goal of the present study is to evaluate the impairment of mental flexibility which occurs in the early stages of AD and its consequences on the driving activity. This work will contribute to improve the knowledge of the role of mental flexibility and of executive functions in general, in the driving activity. The research comprises a twin-approach which combined a neuropsychological evaluation and a driving experiment in a driving simulator. Both the neuropsychological evaluation and the driving experiment involved a mental flexibility activity. The aims of the research are first, to evaluate the level of impairment of mental flexibility in AD, secondly, to assess the mental flexibility in a driving situation, and lastly to evaluate the relationship between the neuropsychological evaluation and performance in the driving simulator.

We chose the driving simulator method for various reasons. First of all, the simulator provides controlled and reproducible situations, which is not possible with real driving situations. Furthermore, other studies [30,31], as well as the authors' previous research protocol [32] verified that experiments on driving simulators were possible both with older drivers and with neurologically impaired patients. Korteling and Kaptein [33] also suggested that experiments on driving simulator should be developed because of the overly wide variability of the real situation studies. Based on this earlier work it was hypothesized that impairment of mental flexibility would have consequences on the flexibility needed for safe driving.

2. Method

2.1. Participants

Ten early Alzheimer's disease (AD) patients took part to the experiment. Their age varied between 65 and 81 years (mean = 74.86, SD = 5.36). In order to include only early AD patients, a Mini Mental State Examination (MMSE, [34]) score of 24 or higher was required for study entry (mean = 24.8, SD = 1.48). All the AD patients still drove their own car at least once a week (minimum of 3000 km/year).

A control group of 29 healthy older drivers (MMSE: mean = 29.65, SD = 0.66) was matched in terms of age (mean = 70.83, SD = 2.95) and education. Participants with medical, substance abuse, neurologic or psychiatric disorders which could account for their cognitive compromise were all excluded.

Participants were excluded if they had suffered a cerebrovascular accident (stroke), traumatic brain injury, or any other type of dementia, or if there was suspicion of dementia for the healthy control group. People with motion sickness or epilepsy were also excluded. All participants had a normal or corrected visual acuity sufficient for driving (binocular acuity >5/10° according to French legislation).

2.2. Procedure

The study presented here is a part of a longer research protocol (for reference: [35,36]). Participants were administered with the neuropsychological tests and the experiment in the driving simulator at IFSTTAR the same day. Institutional review board approval was obtained for all components of the study; information forms were given to the participants.

2.2.1. Neuropsychological evaluation of flexibility

The mental flexibility was assessed by one neuropsychological test: The Plus–Minus Test [37], which consists of 3 lists of 30 two-digit numbers on a single sheet of paper. For the first list, the participants are instructed to add 3 to each number and to write their answers. For the second list, they were instructed to subtract 3 from each number. Finally, for the third list, the participants were required to alternate between adding 3 and subtracting 3 from the numbers. The participants were asked to complete each list as quickly and as accurately as possible.

In this situation, three dependent measures were defined:

- *Response time* (RT, in seconds) to complete the lists of operation: Plus-RT, Minus-RT, Plus/minus-RT,
- *Number of calculation errors* (E) in the completion of the lists (max = 30): Plus-errors: number of errors recorded during the task of addition, Minus-errors: number of errors recorded during the task of subtraction, Plus/minus-errors: number of errors recorded during the alternance task.
- *Shift cost* calculated as the difference between the time to complete the alternating list and the average of the times to complete the addition and subtraction lists.