# Made available by Hasselt University Library in https://documentserver.uhasselt.be

Driving ability in patients with dizziness: a systematic review Peer-reviewed author version

Uwents, Marie-Hélène; Jorissen, Cathérine; Van Ombergen, Angelique; Dobbels, Bieke; van de Berg, Raymond; JANSSENS DE VAREBEKE, Sebastien; Lammers, Marc; ROSS, Veerle; Vanderveken, Olivier; BRIJS, Tom & Van Rompaey, Vincent (2022) Driving ability in patients with dizziness: a systematic review. In: EUROPEAN ARCHIVES OF OTO-RHINO-LARYNGOLOGY, 279 (4), p. 1813-1829.

DOI: 10.1007/s00405-021-06881-8 Handle: http://hdl.handle.net/1942/34249

## Title page

Driving Ability in Patients with Dizziness: a Systematic Review.

#### Authors

Uwents Marie-Hélène, MD<sup>1,2</sup>, Jorissen Cathérine, MD<sup>1,2</sup>, Van Ombergen Angelique, MSc, PhD<sup>2,4</sup>, Dobbels Bieke, MD, PhD<sup>1,2</sup>, van de Berg Raymond, MD, PhD<sup>5,6</sup>, Janssens de Varebeke Sebastien, MD<sup>2,3</sup>, Lammers Marc, MD, PhD<sup>1</sup>, Ross Veerle, PhD<sup>7</sup>, Vanderveken Olivier, MD, PhD<sup>1,2</sup>, Brijs Tom, PhD<sup>7</sup>, Van Rompaey Vincent, MD, PhD<sup>1,2</sup>

#### Affiliations

<sup>1</sup>Antwerp University Hospital, Department of Otorhinolaryngology and Head & Neck Surgery, Edegem, Belgium.

<sup>2</sup>Faculty of Medicine and Health Sciences, University of Antwerp, Belgium.

<sup>3</sup>Jessa Hospital, Department of Otorhinolaryngology and Head & Neck Surgery, Hasselt, Belgium.

<sup>4</sup>Human Research, European Space Agency

<sup>5</sup>Department of Otorhinolaryngology and Head and Neck Surgery, Division of Balance Disorders, Maastricht University Medical Center, School for Mental Health and Neuroscience, Maastricht, Netherlands

<sup>6</sup>Faculty of Physics, Tomsk State Research University, Tomsk, Russian Federation

<sup>7</sup>UHasselt, School of Transportation Sciences, Transportation Research Institute (IMOB), Agoralaan, Diepenbeek, Belgium.

# **Corresponding Author:**

Prof. dr. Vincent Van Rompaey

Antwerp University Hospital

Dept. of Otorhinolaryngology and Head & Neck Surgery

Wilrijkstraat 10, 2650 Edegem, Belgium

+32/3.821.47.30

+32/3.825.05.36

vincent.van.rompaey@uza.be

Requests for reprints should be sent to this address.

Conflicts of interest and source of funding: None declared.

Acknowledgements: none.

#### 1 Abstract

Introduction- Dizziness is considered one of the most common symptoms in general medical practice. Patients can suffer from a wide range of symptoms that are highly relevant while driving and may affect driving ability. In most countries driving restrictions have been suggested for patients with dizziness or a vestibular disorder. However, these restrictions are not always evidence-based and differ significantly between European countries.

Objective- The aim of this systematic review was to identify and evaluate studies dealing with
driving performance of dizzy patients or patients with a vestibular disorder.

9 Methods- A systematic review was performed according to the Preferred Reporting Items for 10 Systematic Reviews and Meta-analysis guidelines. (1) Data sources: PubMed and the reference 11 list of the included articles. (2) Study selection: articles about driving ability and reported 12 driving difficulties in patients with dizziness, or a diagnosed vestibular disorder, were included. 13 (3) Data extraction was performed by two independent authors using predefined data fields: 14 patient's characteristics, diagnostic criteria, sample size, type of evaluation of driving ability 15 and outcome of the study. The protocol (ID 178086) is available online at PROSPERO.

16 Results- Eight out of 705 articles matched the inclusion criteria but varied widely regarding the 17 study population, study design and outcome measures. The majority of studies reported a 18 negative impact of dizziness and/or vestibular disorders on self-reported driving ability and car 19 accidents. Yet several studies could not identify any impairment of driving ability.

Conclusions Driving ability was negatively affected by dizziness or a vestibular disorder in the majority of included studies with low risk of bias. This systematic review revealed a significant heterogeneity in reporting driving performance and contradictory results. We were therefore unable to identify a causal relationship between dizziness and driving ability. There is a need for prospective studies in populations with different vestibular disorders using subjective and objective outcome measures that have been validated to evaluate driving performance.

#### 26 Introduction

Driving supports the patient's autonomy and stimulates social and professional participation in 27 our society. Imposing driving restrictions should be well considered as it will affect personal 28 autonomy for the benefit of public road safety. Driving is a complex task, combining perceptual, 29 motoric and executive functions. A conceptual model, in which the goals and motives of the 30 driver play an essential role, can be used to describe the driver's task. Decisions during driving 31 can be subdivided in three hierarchical categories: operational (control), tactical (specific 32 situations, maneuvering), strategic (planning) as described by Michon et al. 1985. The first, 33 operational level, includes basic actions for instance steering, braking and changing gears. The 34 second, tactical level is influenced by the specific traffic situations and weather or road 35 36 conditions, decisions in this level include the distance with the car in front and driving speed. The third (and highest) level includes decisions which are made before driving the car for 37 example planning the trip and route, assessing the costs and the risks.<sup>1</sup> The physical and mental 38 health of the driver determines at which level these tasks can be performed. Several medical 39 40 conditions such as dizziness can influence the driving performance.

Dizziness is one of the most frequent symptoms in daily medical practice. Yearly, dizziness 41 affects up to 20% of adults.<sup>2</sup> Dizziness can be caused by various medical conditions, can be 42 triggered or it can arise spontaneously.<sup>3</sup> Vestibular disorders can cause a broad range of 43 symptoms such as dizziness, vertigo, lightheadedness and instability. Several of these 44 symptoms can occur while driving and thus compromise -at least temporarily- the driving 45 ability and may put the patient and their surroundings at risk.<sup>4,5</sup> There is a lack of uniformity 46 regarding driving regulations of the dizzy patient and a lack of consensus for clinicians on how 47 to evaluate driving ability in dizzy patients.<sup>4,6</sup> This can be attributed to discordant literature. For 48 instance, a recent communication of DIZZYNET (a European network initiative for vertigo and 49 50 balance research) with data gathered by an insurance company shows there is no increased risk of traffic accidents in people with acute unilateral vestibulopathy or MD.<sup>7</sup> 51

Traffic safety is prioritized by most governments and includes guidelines and regulations concerning alcohol intoxication, the use of mobile phones and driving restrictions for several conditions such as epileptic seizures, etc. <sup>8-10</sup> Patients with chronic vestibular disorders, such as uncompensated unilateral or bilateral vestibulopathy, encounter postural imbalance, gait unsteadiness and movement-induced oscillopsia. The latter is highly relevant while driving

because it can influence the dynamic visual acuity. Nonetheless no consensus is found in the 57 national driving regulations. An appropriate example of the differences in the national 58 regulations is illustrated by the rules related to vestibular disorders. In Finland, Sweden and 59 Denmark no driving restrictions are present for patients with vestibular disorders, whereas in 60 Germany very strict regulations are present. For example, patients with bilateral vestibulopathy 61 are in general considered as unfit to drive and patients with attacks of vertigo, such as in 62 vestibular migraine or menières disease (MD) should have 2-3 years of attack free intervals 63 before they restart driving.<sup>4</sup> 64

The objective of this systematic review is to identify and critically evaluate studies related to driving performance in dizzy patients or patients with a vestibular disorder and to help defining objective measures and methods towards better regulation of driving restriction for this condition.

## 70 Methods

This systematic review was conducted according to the Preferred Reporting Items for
 Systematic Reviews and Meta-Analyses guidelines (PRISMA 2009).<sup>11</sup>

## 73 Information resources

The search query (Appendix 1) was conducted in the PubMed and Cochrane database on

February 1<sup>st</sup> 2020. In addition, the reference list of the included studies was manually screened.

76 The protocol (ID 178086) is available online at PROSPERO (<u>www.crd.york.ac.uk/prospero</u>).

# 77 Eligibility criteria

- 78 <u>Participants</u>: Studies involving patients with dizziness or patients having a diagnosis of a
- vestibular disorder were included. Adult patients aged 18 years or older were included because
- 80 this is the age at which the driver's license can be achieved in Belgium
- 81 <u>Intervention</u>: Studies assessing on-road driving performance or driving ability using at least one
- question or questionnaire were included. Studies assessing driving ability using drivingsimulation were also accepted.
- 84 <u>Comparator</u>: No restrictions were imposed.
- 85 <u>Outcome</u>: Studies reporting on driving difficulties, driving behavior, measurements during
- 86 driving simulation, safety surrogate indicators and car accidents or a surrogate of car accidents
- 87 were included.
- <u>Study design</u>: Case reports, opinion articles and narrative reviews were excluded because
  objective information is preferred for analysis.
- 90 <u>Publication date</u>: No restrictions were imposed regarding the publication date.
- 91 <u>Language</u>: Articles written in English, French or Dutch.
- 92

# 93 Search strategy

94 The search strategy is indicated in appendix 1. The search was conducted independently by two95 researchers (M.H.U. and V.V.R.).

96

# 97 Data extraction

98 Extraction of data was performed by two independent authors (MHU and VVR) using
99 predefined data fields: (1) characteristics of patients, diagnostic criteria (2) population sample
100 size (3) type of evaluation of driving ability (4) conclusion of the study.

### 101 Risk of bias assessment

| 103 | • | Confounding: confounders are co-variables such as age and gender that may influence          |
|-----|---|--|
| 104 |   | the dependent variable (experiencing dizziness) in relation to the independent variable      |
| 105 |   | (driving difficulties).  |
| 106 | • | Selection bias: when the study population is not truly representative for the entire target  |
| 107 |   | population, selection bias may occur. This type of bias is typical for a case control study, |
| 108 |   | but it is less likely to occur in a cohort study.  |
| 109 | • | Recall bias: when participants recall systematically more or less difficulties with driving  |
| 110 |   | because of their dizziness, recall bias can arise. This is a subcategory of classification   |
| 111 |   | bias.  |
| 112 | • | Performance bias: this bias form arises when there are systematic differences between        |
| 113 |   | the group experiencing dizziness and the comparator group.                                   |
| 114 | • | Bias due to missing data: due to the exclusion of individuals with missing data or           |
| 115 |   | inclusion of data with missing information about driving difficulties, e.g. incomplete       |
| 116 |   | questionnaires, bias can occur.  |
| 117 | ٠ | Detection bias: For instance, questionnaires are subject to detection bias because there     |
| 118 |   | is a risk of missing the outcome of interest. When this happens bias in measurement of       |
| 119 |   | outcomes occurs.   |
| 120 | • | Selection of the reported results: this bias occurs when specific subsets of data are        |
| 121 |   | selectively reported to support a conclusion.  |
| 122 | • | Response bias: when the outcome variable is obtained from a sample of the study              |
| 123 |   | population, for example in case of polls or questionnaire-based enquiries, response bias     |
| 124 |   | may occur. To enable a better interpretation of the results emanating from these studies,    |
| 125 |   | the risk of response bias is defined as low in case of the response rates (RR) was more      |
| 126 |   | than 80%.  |
| 127 |   |  |
|     |   |  |

128 Results

## 129 Study selection

The search strategy identified 705 hits in PubMed, no duplicates were present. After the selection procedure a total of 20 articles were identified for full-text screening. Eventually, 8 studies matched the inclusion criteria. No additional articles were found by searching the bibliographies of the included articles. The flowchart of the selection procedure and the reasons





135

136 Figure 1: selection procedure

#### **138** Information extraction

A comprehensive and detailed overview of the included studies is presented in Table 1. In total 139 8 papers were deemed eligible, reporting on a total of 37.065 participants. The respective study 140 populations were heterogenous, not only in the number of patients [3-29 957] but also in the 141 142 diagnostic criteria used. If patients were categorized in diagnostic subgroups, none of them reported validated diagnostic criteria for each of these categories. The study population was 143 selected based on questionnaires in the two large population-based cohort studies<sup>12,13</sup> and in 144 one study a modified Romberg test as surrogate for vestibular function was used.<sup>14</sup> The majority 145 of the eligible studies used questionnaires about driving habits and motor vehicle accidents to 146 assess driving ability. Additional outcome measurements included head-eye coordination and 147 dynamic visual acuity during an on-road 20-minute driving test<sup>15</sup> and whiplash injuries as a 148 surrogate marker for motor vehicle accidents.<sup>16</sup> None of the included studies used safety 149 surrogate measures as an indicator for traffic safety. 150

#### 151 Summary of included studies

Sindwani et al. (1999), assessed the impact of dizziness on driving ability in an outpatient earnose-throat clinic using a questionnaire. A total of 265 patients presenting with dizziness were included. The multiple-choice survey consisted of questions on demographic data, driving habits, dizziness history, the impact of dizziness on driving, compliance, and the perceived role of doctors in reporting patients who are unfit to drive. Twelve percent of the participants (31/258) reported a car accident injury caused by dizziness. In this survey, chronic and severe dizziness were identified to correlate with a higher risk for traffic accidents.<sup>17</sup>

Cohen et al. (2003), assessed the impact of vestibular disorders on driving ability using the 159 Driving Habits Questionnaire (DBQ) and six additional questions about problems specific to 160 people with vestibular disorders. Examples of specific problems were: pulling over to the 161 roadside due to vertigo, staying inside the driving lane, and parking. A total of 118 patients with 162 a vestibular disorder were included and compared to a control group of healthy subjects. The 163 164 following vestibular disorders were inventoried: chronic vestibulopathy, benign paroxysmal positional vertigo (BPPV), MD and postoperative patients after acoustic neuroma resection or 165 166 vestibular nerve section. Difficulties while driving were reported in specific and complex 167 situations with less or complex visual feedback such as pulling into or out of parking spaces, 168 changing lanes in traffic, staying in lane while driving, checking for traffic before pulling into

an intersection, and driving around a ramped parking garage. MD patients and patients with
 chronic vestibulopathy were most affected by these situations.<sup>18</sup>

MacDougall et al. (2009) assessed the driving ability by analyzing measured point-of-regard 171 (what the driver is looking at and attending to), gaze stability and head movement during a 172 173 driving test. A total of three patients with bilateral vestibulopathy were compared to an agematched control group. Head-eye coordination was measured using a custom-made video eye 174 movement system that measured head, eye, and vehicle movement during a driving test. The 175 point of regard, gaze stability and number and amplitude of head movements during a 20-176 177 minute drive in a civil area did not differ significantly from that of age-matched healthy controls.<sup>15</sup> 178

Ward et al. (2013) assessed the driving ability by analyzing data on driving behavior and motion 179 180 discomfort compiled in a large cross-sectional study, the United States National Health Interview Survey (NHIS, 2008). The authors suggested a survey-based definition of bilateral 181 vestibular hypofunction (BVH). For this survey-based diagnosis all of the following symptoms 182 had to be present: blurred or fuzzy vision when moving their head, feeling off-balance or 183 unsteady, drift to the side when trying to walk straight, having difficulty walking in the dark or 184 walking on uneven ground or surfaces. The dizziness had to be identified as a significant 185 186 impairment with a duration greater than one year and excluding neurologic or visual conditions. Dizziness or balance issues were experienced by 3.411 respondents (14,8%), excluding 187 dizziness caused by alcohol intake. Twelve out of 3411 respondents matched the definition of 188 BVH as described earlier. In total 44% of the 12 BVH patients reported limiting and changing 189 190 driving habits due to the symptoms. Most of these participants experienced motion discomfort, particularly in tunnels, navigating stairs, escalators or moving walkways, or driving along as a 191 passenger.<sup>12</sup> 192

193 Wei and Agrawal (2017) assessed driving ability using a question targeting driving difficulty 194 (How much difficulty do you have driving during the daytime in familiar places?) in a large cross-sectional study (i.e. National Health and Nutrition Examination Survey; NHANES, 2001-195 2004). A total of 3.071 participants, aged 50 years or older, were selected for a clinical 196 197 vestibular examination with the modified Romberg test (Table 1). Answers on the question were dichotomized: no difficulty vs. any difficulty. Of the participants 51,9% (1.592) did not 198 pass the test and 279 (9.1%) answered positive on the Driving Difficulty Question. A 199 multivariate statistical analysis demonstrated a two-fold increase of the odds for driving 200

difficulties in the presence of vestibular dysfunction (OR 2.16-, 95% CI 1.57,2.98). The
prevalence of driving difficulties was influenced by a series of confounders such as gender, age,
ethnicity, education, presenting visual acuity, vestibular function and history of falls. A higher
age and female gender were identified with higher risk to report driving difficulties.<sup>14</sup>

205 Wei and Agrawal (2018) assessed the driving ability by family-reported motor vehicle accidents 206 in the past three months in a large population-based cross-sectional study (i.e. National Health Interview Survey; NHIS, 2016). A total of 30.145 participants completed the Adult Balance 207 Supplement (response rate of 96,5%). Affirmative answers were reported on one of the three 208 vestibular vertigo questions in 14.7% of participants. These questions included the presence of 209 (1) rotational vertigo, (2) positional vertigo or (3) recurrent dizziness with nausea and either 210 oscillopsia or imbalance. Motor vehicle accidents were defined as a binary outcome (no 211 accident versus one or more accidents). An accident was defined as an injury for which medical 212 support is sought and occurred when the participant is the driver of the motor vehicle. In the 213 group with vestibular vertigo, 0.4% had an injury due to a car accident while driving in the past 214 three months. In the control group without vestibular vertigo, this risk was 0.1% (OR 3.5; 95% 215 CI 1.7-7.9).<sup>13</sup> 216

Pyykkö et al. (2019) evaluated driving ability using a non-validated questionnaire on driving 217 avoidance, driving habits and (near-miss) car accidents. A total of 548 MD patients were 218 219 included. In this study, MD patients were found to report fewer traffic accidents annually (0,9%) when compared to a control group of the general population (1,7%). In addition, the 220 lifetime risk of car accidents was lower among subjects with MD (8,3%) compared to the 221 222 control group (24-28%). Some absolutely avoid car driving (8,4%), while 81,4% have other strategies to ensure safe car driving for example driving avoidance during symptoms or in 223 darkness or rain.<sup>19</sup> 224

Huppert et al. (2019) studied driving ability by using whiplash injuries as a surrogate marker 225 for traffic accidents in a retrospective analysis including patients with a diagnosis of vestibular 226 227 neuritis (VN, n=25.448) and MD (n=4.509). Data were extracted from the Barmer health 228 insurance system comparing vestibular neuritis patients with a control group. Because the 229 incidence of whiplash injuries was unchanged before and after the diagnosis of VN and MD, the authors concluded there was no causal association between vestibular disease and higher 230 risk of car accidents and they, therefore, found no reason to restrict these patients from driving. 231 16 232

#### 233 Risk of bias assessment

A methodological quality assessment was limited by a large variability in study designs, study population, inclusion criteria and interventions. For this reason, an alternative approach was used as described in the methods. In the following section the main risks of bias of the 8 selected papers were detailed and these were further summarized in table 2.

| Article                             | Study                        | Bias due to | Selection | Recall | Performance | Bias    | Detection | Reporting | Response | Overall |
|-------------------------------------|------------------------------|-------------|-----------|--------|-------------|---------|-----------|-----------|----------|---------|
|                                     | design                       | confounding | bias      | bias   | bias        | due to  | bias      | bias      | bias     | risk of |
|                                     |                              |             |           |        |             | missing |           |           |          | bias    |
|                                     |                              |             |           |        |             | data    |           |           |          |         |
| Sindwani R. et<br>al., 1999         | Case study                   | +           | +         | +      | 1           | ?       | /         | +         | -        | +       |
| Cohen H.S. et<br>al., 2003          | Case-control<br>study        | -           | +/-       | +/-    | -           | ?       | -         | -         | ?        | +/-     |
| McDougall HG.<br>Et al., 2009       | Case series                  | +/-         | +         | 1      | +/-         | ?       | -         | +         | 1        | +/-     |
| Ward. B.K. et<br>al., 2013          | Cross-<br>sectional<br>study | -           | -         | +      | -           | ?       | -         | -         | 1        | -       |
| Wei E.X. and<br>Agrawal Y.,<br>2017 | Cross-<br>sectional<br>study | +/-         | -         | +      | -           | ?       | -         | -         | 1        | -       |
| Wei E.X. and<br>Agrawal Y.,<br>2018 | Cross-<br>sectional<br>study | -           | -         | +/-    | -           | ?       | -         | -         | -        | -       |
| Pyykko I. et al.,<br>2019           | Case study                   | +           | +/-       | +      | +           | ?       | 1         | -         | +        | +       |
| Huppert D. et<br>al., 2019          | Retrospective cohort study   | +           | +         | 1      | -           | -       | +         | -         | 1        | +/-     |

238

Table 2. Risk of Bias assessment: +, high risk of bias; +/-, intermediate risk of bias; -, low risk of bias; ?,
bias cannot be evaluated because lack of information; /, type of bias not applicable to study.

The following limitations were identified in the study of Sindwani et al. (1999). As such with 241 respect to the study population, both an age distribution and a control group were missing. 242 Further selection bias may have been occurred as the study population included only patients 243 from an ear-nose-throat clinic. Hence for those subjects it is more likely that they are suffering 244 from severe and chronic dizziness than the general patient population. Moreover, non-validated 245 questionnaires were used which results in a high risk of recall bias. Additionally, as at least 1 246 of the 5 items of the applied questionnaires were not included in the result section, reporting 247 bias was evaluated as high. On the contrary, the gender distribution was nearly equal, hence 248

this was not likely to be a confounding factor. Further with a response rate of 97%, the risk of
response bias was low. Finalluy, the risk of bias due to missing data was low as no missing data
were reported.<sup>17</sup>

In the study of Cohen et al. (2003) an uneven gender distribution was considered with a 252 253 female/male distribution of nearly 2:1. Further this unequal gender distribution was not taken into account in the analysis of the results and conclusions. This could lead to confounding bias. 254 On the contrary no significant differences among the diagnostic and control group were present 255 in respect to age (p=0,607) and gender (p=0,224), resulting in a low risk of performance bias. 256 A validated questionnaire (i.e. DHQ) was used, hence there was an intermediate risk of recall 257 bias. Bias due to missing data was unaddressed as no information was reported regarding 258 259 incomplete questionnaires.<sup>18</sup>

The study of MacDougall et al. (2009) was more prone for selection bias due to the small sample size (n=3) considered in their study. Further a potential confounding factor was the small age range of the test and the age-matched control group (63-69y). Moreover ,performance bias may have been occurred as the control group was not matched to gender. In the results of their study a high risk of reporting bias was present as no measurements regarding point of regard and gaze stability were given in the result section.<sup>15</sup>

266 A low overall risk of bias was evaluated in three large cross-sectional studies: (1) Ward et al. (2013), (2) Wei E. and Agrawal Y. (2017), (3) Wei E. and Agrawal Y. (2018). Still due to the 267 study design (cross-sectional) no causal relationships could be determined. Furthermore a 268 potential confounder of the study of Ward et al. (2013) include the unequal gender distribution 269 270 in which more female than male (89/11) participants are included.<sup>12</sup> Next, in the study of Wei E. and Agrawal Y (2017), a risk of detection bias was the estimation of vestibular function by 271 the modified Romberg test which was considered as an aspecific physiologic test of peripheral 272 vestibular function.<sup>14</sup> In the study of Wei E. and Agrawal Y. (2018) motor vehicle accidents 273 274 could be missed by recall bias or when the accidents were not associated with an injury. In 275 addition, no objective measurements of peripheral vestibular function were performed in their 276 study. The risk of detection bias was low because the questions were completed by proxy 277 respondents (i.e. a family member). Finally, there was a low risk of response bias based on a RR of 96.5%.<sup>13</sup> 278

- In the study of Pyykkö et al. (2019) an unequal gender distribution in the study population (i.e.
  female/male patients = 411/137) results in a risk of bias. Further age has not been reported
  which was regarded as a potential confounder.
- An intermediate risk of selection bias was scored because only patients of the Finnish MD association are included in this study which is a selected subgroup of patients. Moreover, recall bias could not be excluded in the study design as the study is based on questionnaires. Finally, there was a high risk of response bias based on a RR of 58.7%.<sup>19</sup>
- A risk of bias in the study of Huppert et al. (2019) was evaluated based on the assumptions made in their study. As such patients diagnosed with MD and VN were selected based on the data of a statutory health insurer. Moreover, in this patient population whiplash injuries were
- accounted as surrogate for traffic accidents without considering the actual cause of the whiplash
- 290 injury. This could lead to detection bias. At last potential confounding factors such as age and
- 291 gender of the patients were not reported nor included in the analysis of this study.<sup>16</sup>

#### 292 Discussion

This study aimed to systematically review available literature on driving performance in dizzy 293 patients or patients with a vestibular disorder. According to most papers included in this study, 294 295 it was concluded that dizziness has a negative impact on the driving performance. This was also confirmed by three large cross-sectional studies for which a low risk of bias was evaluated. 296 297 Nonetheless also two of the included studies in this literature review did not observe any impact on driving performance. However, a higher risk of bias was observed in these studies. 298 Moreover, in one of the studies a rather positive effect of a vestibular disorder on driving ability 299 was present.<sup>19</sup> The latter could be attributed to the adjustment of the patients driving habits (e.g. 300 limited car driving, only car driving during daytime) due to their vestibular symptoms. We were 301 unable to demonstrate a causal relationship between dizziness and driving performance due to 302 significant heterogeneity. For example, none of the studies used Barany society diagnostic 303 304 criteria for including patients.

305 Remarkably, in all but one of the studies more female than male patients were included. E.g. the study of McDougall et al. only included 3 male patients.<sup>15</sup> Note that gender distribution is 306 generally considered as a potential confounder and bias could arise when this is not taken into 307 account in the analysis. Furthermore, in the study of Wei E. and Agrawal Y. (2017), female 308 patients with vestibular vertigo indicated difficulties with driving more frequently compared to 309 310 male patients (p 0,0013). Nonetheless when looking at the relationship between gender and the amount of car accidents Wei E. and Agrawal Y. (2018) concluded that no significant difference 311 could be found between both genders (p 0,424). Hence, the included studies reveal that there is 312 a difference related to gender, in how the patients evaluate their driving capability but not in 313 the amount of car accidents. 314

According to Michon's model, most of the difficulties reported by the patient population are 315 related to the first (operational) or second (tactical) level of the driving task. For example, due 316 to the absence of the vestibulo-ocular-reflex in patients diagnosed with bilateral vestibulopathy, 317 these patients experience difficulties to read and process stationary signs while driving or sitting 318 in a driving car. Additionally, due to reduced spatial orientation difficulties are also experienced 319 by these patients when changing traffic lanes or during parking. <sup>20-22</sup> Moreover conditions 320 321 limiting the visual input of the patients such as driving at night or driving in heavy rain can 322 impair the driving performance further at that moment.

Besides dizziness, other confounders may influence driving ability: anxiety, attention, age, gender and drugs (antidepressants,..). First of all, driving anxiety is experienced by many older adults, especially in female drivers.<sup>23</sup> A large proportion of female patients report high levels of driving anxiety and associated differences in driving patterns, e.g. drive less often, drive over shorter distances or use alternative transportation modes.<sup>23,24</sup>

Secondly attention capacity has been reported as an important factor for driving<sup>25</sup>, a factor that has been demonstrated to be significantly impaired, especially in patients with bilateral vestibulopathy.<sup>26-29</sup> Attentional deficits may influence cognitive and motor dual tasks which are relevant while driving.<sup>24,25,30-32</sup>

Although conflicting data have been published on driving performance in stable outpatients, which are treated for depression<sup>33</sup>, antidepressant medication is known to influence driving ability.<sup>34</sup> Two recent systematic reviews have studied the correlation between antidepressant drug use and driving.<sup>35,36</sup> Although the studies indicated a negative effect of antidepressants on driving performance, the epidemiological designs could not exclude the possibility that the underlying illness, generally a major depression, is the culprit. Additive effects with alcohol were most pronounced with sedating antidepressants.

At present efforts have been made to develop screening procedures to save part of the at-risk elderly driver population from stressful and costly on-road driving evaluations.<sup>37</sup> Similar efforts would be essential to evaluate individual driving ability in the patient population that report vestibular symptoms. Patients should be informed of the potential risk of driving when experiencing dizziness or having been diagnosed with a vestibular disorder.<sup>5</sup>

Even if dizziness can be considered as causing driving disability, it is unclear whether it can be
identified as the main factor and to which extent it may influence driving ability in general.
Consequently further research is suggested.

#### 347 Future research directions

To make further conclusions about driving ability in patients experiencing dizziness or patients
diagnosed with vestibular disorders, further studies are suggested, using more objective
subgroups for example defined by the Barany society criteria.

These additional studies would allow to evaluate the relationship between driving ability and vestibular disorders further in a more comprehensive and objective way. As such based on additional research an evaluation could be made for each vestibular disorder to what extent the disorder influences the driving ability of the patient. These results could then help governments to enhance and update driving regulations.

For the additional studies it is suggested to use as secondary endpoints; (1) traffic safety surrogate markers and (2) self-reported driving ability evaluated by well-defined and validated questionnaires. The primary endpoint on the other hand could be the amount and severity of traffic accidents.

#### 360 Conclusion

This study aimed to systematically review available literature on driving performance in dizzy 361 patients or patients with a vestibular disorder. A negative impact of dizziness or a vestibular 362 disorder on driving ability was revealed in most of the studies. This conclusion was also 363 confirmed by three large cross-sectional studies for which a low risk of bias was observed. 364 Nonetheless many studies included in this systematic review were highly heterogeneous in 365 respect to the study population, the study design and the outcome measurements. Therefore, no 366 causal relationship could be identified. Based on this systematic review, we identified a need 367 for prospective studies in populations with different vestibular disorders (vertigo spells versus 368 chronic dizziness). These studies should ideally use subjective and objective outcome measures 369 370 that have been validated for their ability to evaluate driving performance.

- 371 Appendices
- 372

# 373 Appendix 1

- The following search strategy was used: (("vertigo"[MeSH Terms] OR "vertigo"[All Fields])
- 375 OR ("vertigo"[MeSH Terms] OR "vertigo"[All Fields] OR "dizziness"[All Fields] OR
- 376 "dizziness"[MeSH Terms]) OR vestibular[All Fields]) AND (("drive"[MeSH Terms] OR
- 377 "drive"[All Fields]) OR ("automobile driving"[MeSH Terms] OR ("automobile"[All Fields]
- AND "driving"[All Fields]) OR "automobile driving"[All Fields] OR "driving"[All Fields]) OR
- 379 (fitness[All Fields] AND ("drive"[MeSH Terms] OR "drive"[All Fields]))).

### 381 References

- Michon J. chapter A critical view of driver behavior models: what do we know, what should
   we do? In: L. Evans RS, ed. *Human behavior and traffic safety*. New York: Plenum
   Press1985:page 485-520.
- Neuhauser HK. The epidemiology of dizziness and vertigo. *Handb Clin Neurol.* 2016;137:67 82.
- 387 3. Newman-Toker DE, Edlow JA. TiTrATE: A Novel, Evidence-Based Approach to Diagnosing
   388 Acute Dizziness and Vertigo. *Neurol Clin.* 2015;33(3):577-599, viii.
- Huppert D, Straumann D, Magnusson M, Pyykko I, Brandt T. Dizziness in Europe: from
   licensed fitness to drive to licence without fitness to drive. *J Neurol.* 2018;265(Suppl 1):9-17.
- Sinnott JD, Mahoney H, Wilkinson AS, Broomfield SJ. Dizziness, driving, and the Driver and
   Vehicle Licensing Agency: audit of advice given to patients, and design of a patient
   information leaflet. J Laryngol Otol. 2019:1-3.
- Evans A, Eng CY. Driving and otolaryngology: do we know the rules? *J Laryngol Otol.* 2006;120(3):181-184.
- Zwergal A, Grill E, Lopez C, Dieterich M. DIZZYNET 2019: approaching the future of vestibular
   research. *J Neurol.* 2019;266(Suppl 1):1-2.
- 3988.Ji Kwon N, Han E. A review of drug abuse in recently reported cases of driving under the399influence of drugs (DUID) in Asia, USA, and Europe. Forensic Sci Int. 2019;302:109854.
- 400 9. Overton TL, Rives TE, Hecht C, Shafi S, Gandhi RR. Distracted driving: prevalence, problems,
  401 and prevention. *Int J Inj Contr Saf Promot.* 2015;22(3):187-192.
- 402 10. Mazzariol B, Pastorini A, di Luca A, di Luca NM. Recent Medico-Legal Developments on the
  403 Issue of Epilepsy and Driver's License Requirements in the Italian and European Legislation.
  404 Behav Neurol. 2019;2019:7127956.
- 405 11. Moher D, Liberati A, Tetzlaff J, Altman DG. Preferred reporting items for systematic reviews
  406 and meta-analyses: the PRISMA statement. *Int J Surg.* 2010;8(5):336-341.
- 407 12. Ward BK, Agrawal Y, Hoffman HJ, Carey JP, Della Santina CC. Prevalence and impact of
  408 bilateral vestibular hypofunction: results from the 2008 US National Health Interview Survey.
  409 JAMA Otolaryngol Head Neck Surg. 2013;139(8):803-810.
- 410 13. Wei EX, Agrawal Y. Association Between Vestibular Vertigo and Motor Vehicle Accidents:
  411 Data From the 2016 National Health Interview Survey. *Ear Hear.* 2018;39(6):1232-1235.
- 412 14. Wei EX, Agrawal Y. Vestibular Dysfunction and Difficulty with Driving: Data from the 2001413 2004 National Health and Nutrition Examination Surveys. *Front Neurol.* 2017;8:557.
- MacDougall HG, Moore ST, Black RA, Jolly N, Curthoys IS. On-road assessment of driving
   performance in bilateral vestibular-deficient patients. *Ann N Y Acad Sci.* 2009;1164:413-418.
- 416 16. Huppert D, Straube A, Albers L, von Kries R, Obermeier V. Risk of traffic accidents after onset
  417 of vestibular disease assessed with a surrogate marker. *J Neurol.* 2019;266(Suppl 1):3-8.
- 418 17. Sindwani R, Parnes LS, Goebel JA, Cass SP. Approach to the vestibular patient and driving: A
  419 patient perspective. *Otolaryngol Head Neck Surg.* 1999;121(1):13-17.
- 420 18. Cohen HS, Wells J, Kimball KT, Owsley C. Driving disability and dizziness. *J Safety Res.*421 2003;34(4):361-369.
- 422 19. Pyykko I, Manchaiah V, Zou J, Levo H, Kentala E. Driving Habits and Risk of Traffic Accidents
  423 among People with Meniere's Disease in Finland. *J Int Adv Otol.* 2019;15(2):289-295.
- 42420.Dobbels B, Mertens G, Gilles A, et al. The Virtual Morris Water Task in 64 Patients With425Bilateral Vestibulopathy and the Impact of Hearing Status. Front Neurol. 2020;11:710.
- 426 21. Dobbels B, Lucieer F, Mertens G, et al. Prospective cohort study on the predictors of fall risk
  427 in 119 patients with bilateral vestibulopathy. *PLoS One.* 2020;15(3):e0228768.
- 428 22. Lucieer FMP, Van Hecke R, van Stiphout L, et al. Bilateral vestibulopathy: beyond imbalance
  429 and oscillopsia. *J Neurol.* 2020.
- 430 23. Taylor JE, Connolly MJ, Brookland R, Samaranayaka A. Understanding driving anxiety in older
  431 adults. *Maturitas.* 2018;118:51-55.

432 24. Danneels M, Van Hecke R, Keppler H, et al. Psychometric Properties of Cognitive-Motor Dual-433 Task Studies With the Aim of Developing a Test Protocol for Persons With Vestibular 434 Disorders: A Systematic Review. Ear Hear. 2020;41(1):3-16. 435 25. Cuenen A, Jongen EM, Brijs T, et al. Does attention capacity moderate the effect of driver 436 distraction in older drivers? Accid Anal Prev. 2015;77:12-20. 437 26. Dobbels B, Mertens G, Gilles A, et al. Cognitive Function in Acquired Bilateral Vestibulopathy: 438 A Cross-Sectional Study on Cognition, Hearing, and Vestibular Loss. Front Neurosci. 439 2019;13:340. 440 27. Dobbels B, Peetermans O, Boon B, Mertens G, Van de Heyning P, Van Rompaey V. Impact of 441 Bilateral Vestibulopathy on Spatial and Nonspatial Cognition: A Systematic Review. Ear Hear. 442 2019;40(4):757-765. 443 28. Lacroix E, Deggouj N, Salvaggio S, Wiener V, Debue M, Edwards MG. The development of a 444 new questionnaire for cognitive complaints in vertigo: the Neuropsychological Vertigo 445 Inventory (NVI). Eur Arch Otorhinolaryngol. 2016;273(12):4241-4249. 446 29. Guidetti G, Guidetti R, Manfredi M, Manfredi M. Vestibular pathology and spatial working 447 memory. Acta Otorhinolaryngol Ital. 2020;40(1):72-78. 448 30. Ross V, Jongen E, Brijs T, Ruiter R, Brijs K, Wets G. The relation between cognitive control and 449 risky driving in young novice drivers. Appl Neuropsychol Adult. 2015;22(1):61-72. 450 31. Ross V, Jongen EMM, Brijs K, Brijs T, Wets G. Investigating risky, distracting, and protective 451 peer passenger effects in a dual process framework. Accid Anal Prev. 2016;93:217-225. 452 32. Ross V, Vossen AY, Smulders FTY, et al. Measuring working memory load effects on 453 electrophysiological markers of attention orienting during a simulated drive. Ergonomics. 454 2018;61(3):429-443. 455 33. Miyata A, Iwamoto K, Kawano N, et al. Driving performance of stable outpatients with 456 depression undergoing real-world treatment. Psychiatry Clin Neurosci. 2018;72(6):399-408. 457 34. Brunnauer A, Laux G, Geiger E, Soyka M, Moller HJ. Antidepressants and driving ability: 458 results from a clinical study. J Clin Psychiatry. 2006;67(11):1776-1781. 459 35. Brunnauer A, Laux G. Driving Under the Influence of Antidepressants: A Systematic Review 460 and Update of the Evidence of Experimental and Controlled Clinical Studies. 461 *Pharmacopsychiatry*. 2017;50(5):173-181. 462 36. Cameron DH, Rapoport MJ. Antidepressants and Driving in Older Adults: A Systematic 463 Review. Can J Aging. 2016;35 Suppl 1:7-14. 464 37. Urlings JHJ, Cuenen A, Brijs T, Lutin M, Jongen EMM. Aiding medical professionals in fitness-465 to-drive screenings for elderly drivers: development of an office-based screening tool. Int 466 *Psychogeriatr.* 2018;30(8):1211-1225.