Scientific Reports

https://doi.org/10.1038/s41598-026-53327-4

Article in Press

Assessing the relationships between migraine and driving risks, challenges and coping strategies

Received: 28 August 2025

Accepted: 12 May 2026

Published online: 14 June 2026

Cite this article as: Genc H., Ghouri R., Ozdemir A.A. *et al.* Assessing the relationships between migraine and driving risks, challenges and coping strategies. *Sci Rep* (2026). https://doi.org/10.1038/s41598-026-53327-4

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Title: Assessing the Relationships between Migraine and Driving Risks, Challenges and Coping Strategies

Short Title: Mig-drive Study

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ABSTRACT

Driving is a multitasking activity that requires sustained attention, multisensory integration, and rapid reaction capacity. This study aims to assess the under-recognized disability experienced during driving in individuals with migraine, the outcomes of symptoms triggered during driving on safety, and the coping strategies employed. This cross-sectional study included individuals between the ages of 18 and 65 diagnosed with migraine according to the International Classification of Headache Disorders-3 criteria. A structured form, based on the "Driving Habits Questionnaire," was applied to patients by 57 neurologists face-to-face. It

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covered parameters such as demographics, headache characteristics during driving, sensitivity to driving, coping strategies, the Headache Impact Test-6, driving cessation, and traffic accidents. The patients were divided into diagnostic subgroups: those with/without aura, episodic/chronic, and those with and without vestibular migraine by headache experts. Additionally, we employed a Structural Equation Model (SEM) to identify the variables that influence driving cessation and accidents. Of the 2,522 patients evaluated, 1,333 (mean age: 36.75 ± 9.53 years; 64.4% female) had an active driving history. Patients experienced headaches in 13% of their active driving sessions, and 70.6% had experienced a headache while driving at least once during their active driving sessions. Due to migraine, 1.7% of the patients ceased driving, and 9.2% reduced their driving frequency. The mean age of the drivers who had an accident was younger [35.3133; 95% CI: 34.1677-36.4589, p = 0.007]. Headaches during driving were mainly associated with decreased attention (69%), restlessness (66%), and nervousness (56%). To cope with headaches, drivers most often preferred to use analgesics/triptans (58.8%), turn off the music (51.9%), and wear sunglasses (47.7%). SEM revealed causal relationships between migraine subtypes, symptoms, road conditions affecting driving sensitivity, the impact of headaches on driving, direct and indirect cessation of driving, and accident probability. Our findings demonstrated that driving is an underrecognized factor that can cause insidious disability in patients with migraine and may pose a threat to driving safety, often underappreciated in clinical care and traffic regulations. Raising awareness about migraine-related driving impairments and enhancing coping mechanisms may reduce preventable risks and improve the quality of life for affected individuals.

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Keywords: Migraine, driving, driving cessation, accident, road conditions, headache

INTRODUCTION

Migraine impacts various aspects of daily life, including driving [1]. In a study conducted in Italy, approximately 20% of migraine patients reported severe limitations in driving due to migraine, while approximately 15% reported serious problems with driving performance [2]. Considering the cognitive, visual, and vestibular symptoms associated with migraine [3], it is not unexpected that driving ability may be affected [4]. Migraine headache is associated with central sensory processing and multisensory integration dysfunction. Sensory processing, particularly in the visual system of the brain, is disturbed in more than one domain in migraine patients [5-8]. The integration of incoming somatosensory input with descending

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motor output is disrupted during migraine attacks, revealing ictal facilitation in the sensorimotor cortex beginning from the preictal phase [9]. Another subtype that may affect driving is vestibular migraine (VM), whose lifetime prevalence is estimated to be 1% [10]. Patients may experience spontaneous, positional, visual, or head movement-triggered vertigo, as well as transient auditory symptoms [11]. Moreover, visual and postural motion and a visually busy environment evoked vestibular symptoms, which are predominant in migraine patients [12]. Another factor that may have an impact on driving is chronic migraine (CM), and it was reported that some people with migraine avoid driving as the pain intensity increases [13]. Nevertheless, all this information, the dimensions, determinants, and effects of migraine on driving have not been sufficiently investigated and documented, highlighting the need for further research in this area.

The primary purposes of this study were to evaluate driving cessation and accident rates in patients with migraine. Secondary purposes included determining factors such as road conditions that trigger or exacerbate headaches in patients, the effects of attacks on patients while driving, and how patients cope with headaches.

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METHODS

This study employed a hospital-based, multicenter, cross-sectional design from May to July 2024. A structured questionnaire form based on the "Driving Habit Questionnaire" [14] was used by 57 neurologists working in 40 different clinics to collect the data **[Supplementary files 1 and 2]**. Physicians administered the questionnaires via face-to-face interviews after obtaining consent. The entire questionnaire application time was approximately 30 minutes.

The first section consisted of 21 questions that evaluated the patients' demographic characteristics, migraine and aura subtypes, headache characteristics, and treatment. The second section included 53 questions regarding the individuals' experiences with driving, preferences and behaviors, possible migraine triggers, headache coping strategies, driving cessation, and traffic accident history. During driving, patients' sensitivity to road conditions, whether they had a headache or not, was rated on a Likert-type scale from 0 (I have no difficulty) to 5 (I have significant difficulty). The parameters questioned consisted of questions regarding weather conditions (rainy, snowy, icy, and foggy), ground characteristics (asphalt, path, muddy, intersections, highways or intercity, roads without traffic lights/warning signs), driving time (daytime, nighttime, and work hours), and driving

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maneuvers (left turn, parallel parking). Again, the effects of factors likely to cause or increase headaches during the journey were questioned on the same scale. The parameters included light sources in road conditions that may trigger a migraine attack or increase the severity of pain (sunlight setting between rows of trees, light-emitting diode (LED) headlights, signal lights, brake lights, etc.), sound sources (heavy traffic, listening to loud music, siren sounds,), flicker sources, odor sources (vehicle-fuel smell, cigarette smell, etc.) and other conditions (heavy traffic (stress factor), rough roads).

The disability level of drivers with migraine was assessed in the third section using the Headache Impact Test-6 (HIT-6) [15].

Based on a prevalence rate of 24.9% in neurology outpatient clinics [16], the G*Power analysis calculated that a minimum of 1337 patients should be included in the study with a 2% margin of error. All volunteer patients with migraine were included in the study period, not emergency referrals—90,7% of patients were primarily admitted to the clinic with headache complaints. The primary complaint of the rest of them usually became an accompanying symptom to headache, such as headache, vertigo, dizziness, or neck pain. A total of 2,548 migraine patients were screened, and twenty-six individuals whose data were questionable in cross-checks were excluded from the study. The flowchart of the study was summarized in **Figure 1**.

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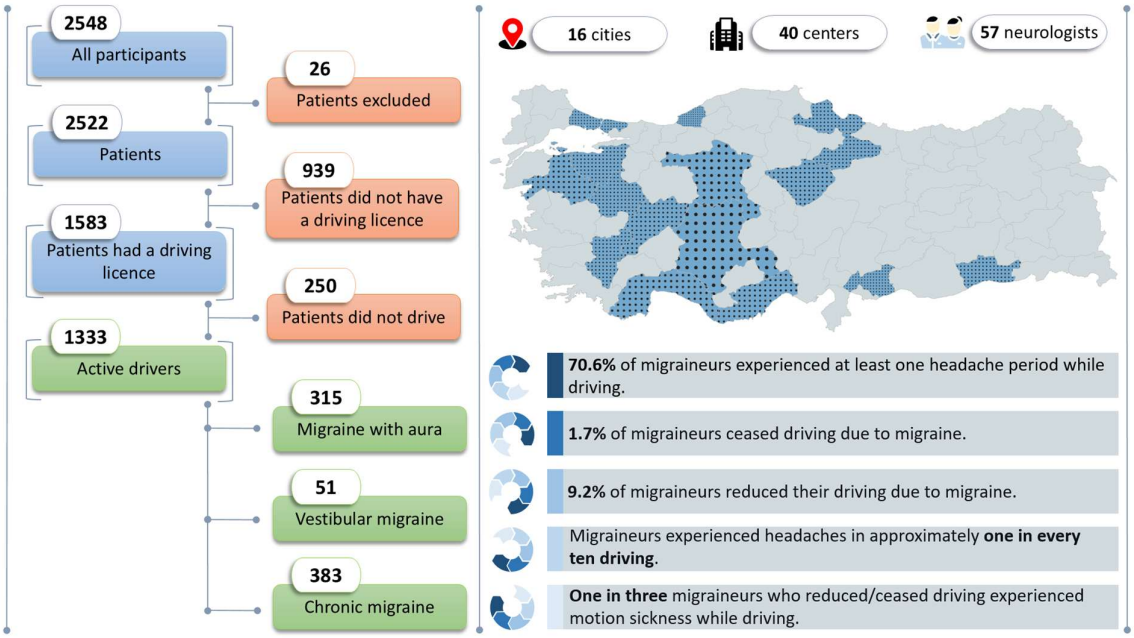


Figure 1: *Flowchart of the study, patients' distributions, and study highlights*

Informed consent was obtained from participants via an online process. All methods were performed in accordance with the relevant guidelines and regulations and the Declaration of Helsinki. The short name of the study was determined as *"Mig-Drive,"* and its content was approved by the Medical Research Ethics Committee [ATADEK - Decision no: 2024-5/204 **(Supplementary file 3)]**.

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Inclusion Criteria

• Being between 18 and 65 years of age

• Having a definite diagnosis of migraine according to ICHD-3 by a neurologist [11].

Exclusion Criteria

• Individuals who were <18 years and >65 years

• Not having a definite diagnosis of migraine according to ICHD-3 criteria by a neurologist

Patients included in the study were divided into subgroups as follows (Overlapping may occur);

• Migraine with/without aura (MwA/MwoA),

• Episodic/chronic migraine (EM/CM),

• With/without vestibular migraine (VM),

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• With/without headache while driving,

Headache Impact Test (HIT-6)

The HIT-6 is a valid, brief, and structured questionnaire designed to measure the impact of migraine, including the time lost from daily activities from the patient's perspective [17,18]. It comprises six items that cover various life domains, and each item is scored on a five-point Likert-type scale. Increasing scores indicate an increased impact of headaches on the patient. The Turkish validity and reliability study of the test was conducted by Dikmen et al. [19].

Statistical methods

The normality of continuous variables was assessed using the Shapiro-Wilk test. Parametric tests were applied for normally distributed variables, while non-parametric tests were used for non-normally distributed data. Group comparisons between migraine subtypes were performed using an Independent-Samples t-test or a Mann-Whitney U test, as appropriate. Categorical variables were analyzed using the Chi-square test or Fisher's exact test. To explore the direct and indirect relationships among migraine subtypes (MwA, VM, CM), accompanying symptoms, driving-related headache, sensitivity to road conditions, traffic accident history, and driving cessation, Structural Equation Modeling (SEM) was conducted.

SEM is a powerful multivariate analysis technique used for many purposes. One of them is causal modelling or path analysis. In path analysis, causal relationships between variables were investigated. In structural equation modeling, path diagrams illustrate which variables cause changes in other variables. In the path diagram, variables are endogenous or exogenous. While exogenous variables are measured outside the model, endogenous variables can be thought of as dependent variables and their measure are determined in the model. They can be either manifest or latent variables. Manifest variables are represented in squares or rectangles, and latent variables are in ovals or circles. Lines and arrows show direct and indirect relationships between these variables.

In this study, structural equation modeling was used to identify the factors directly and indirectly associated with accidents and driving release. Since the assumption of multivariate normality was not met, parameter estimates were obtained using the asymptotic distribution-free (ADF) Gramian method. The Root Mean Square Error of Approximation (RMSEA) and the Jöreskog Goodness-of-Fit Index (GFI) were used to assess the model's goodness of fit.

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RMSEA values between 0.05 and 0.08 indicate an acceptable fit, and less than 0.05 indicates a good fit. A GFI value closer to 1 indicates a better fit of the data.

Migraine characteristics and accompanying symptoms were modeled as exogenous latent variables, while road condition sensitivity, driving-related headache, traffic accidents, and driving cessation were considered endogenous latent variables. The strength and direction of the associations were reported using standardized beta coefficients (β), and p-values < 0.05 were considered statistically significant. RMSA value regarding accident ratio was 0.066, and regarding driving cessation was 0.069. Path diagrams were used to illustrate the structural relationships and mediation effects within the model. All statistical analyses were performed using R software, with a significance level set at 0.05.

RESULTS

The average age of the 1,333 drivers was 36.75±9.53, and 64.4% were female. Patients drove an average of 19.1 times per month and experienced headaches on 13.02% of these drives **(Figure 1)**. Headache attacks during driving lasted an average of 3.36 hours, and the pain intensity was 6.0 (overall pain intensity: 7.5) **(Table 1)**. Headaches during driving caused 31% of the patients to worry about being involved in an accident. 17.6% of drivers with migraine had been involved in at least one traffic accident in the previous year. Of the 1,333 drivers, 5.6% stated that they had ceased driving, while 1.7% had made this decision directly due to migraine. In addition, 122 patients (9.2%) had reduced their driving frequency due to migraine **(Table 1)**.

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The average age of those who had an accident was 35.3 [95% CI: 34.1677-36.4589, p=0.007]. 18.2% of patients experienced motion sickness while driving, and the accident rate was higher among these patients (24.2% of those with an accident) (p=0.008). Individuals who experienced motion sickness while driving had a higher rate of ceasing or reducing driving due to migraine (33.3% of those who ceased/reduced driving reported motion sickness while driving, p<0.001).

The sensitivity of individuals with migraine to road conditions while driving was significantly increased in the presence of a headache **(Figure 2)**. While patients' sensitivity showed a more pronounced response to weather conditions (icy, foggy, and snowy weather, respectively), sensitivity to left turns, intersections, and asphalt roads was less pronounced.

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Headaches while driving cause many problems for drivers, including decreased attention (69%), followed by restlessness (66%) and irritability (56%) **(Table 2)**. When drivers experienced headaches, they most frequently used analgesics or specific attack medications to cope with the pain (58.8%). Additionally, 51.9% of patients turned off the music, and 47.7% wore sunglasses. Other methods of coping with pain are summarized in **Table 3**.

The distribution of comorbid conditions among driver patients with migraine was illustrated in the **Supplementary file 4**. When examining psychiatric comorbidities in the study participants, 8.9% of them had depression, and 14.1% had anxiety disorder. Only one patient was diagnosed bipolar disorder. There was no significant relationship between depression and anxiety in terms of driving cessation, accident ratio, and headache related to driving among migraineurs ($p>0.05$).

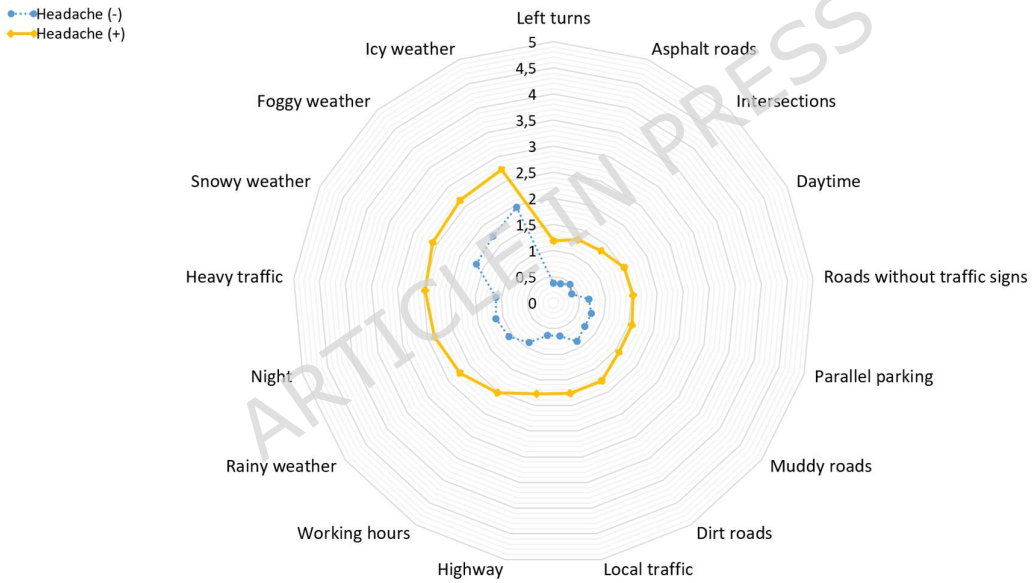


Figure 2: *Spiderweb diagram illustrating drivers' sensitivity to road conditions in all patients with migraine (n = 1333). The presence of a headache significantly increases the sensitivity to driving and/or road conditions ($p < 0.05$ in all conditions). [The severity score ranges from 0 (no difficulty) to 5 (significant difficulty).]*

Driving Behaviors and Clinical Features in Patients with Migraine with Aura

MwA was found in 23.6% of drivers who experience migraines. Among these individuals, 95.2% reported experiencing visual aura, while 28.6% reported sensory aura. The clinical

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characteristics, the challenges headaches can pose while driving, and the coping strategies employed by drivers were summarized in **Tables 1** to **3**. Additionally, the drivers' sensitivity to different road conditions was illustrated in **Figures 3** and **4**.

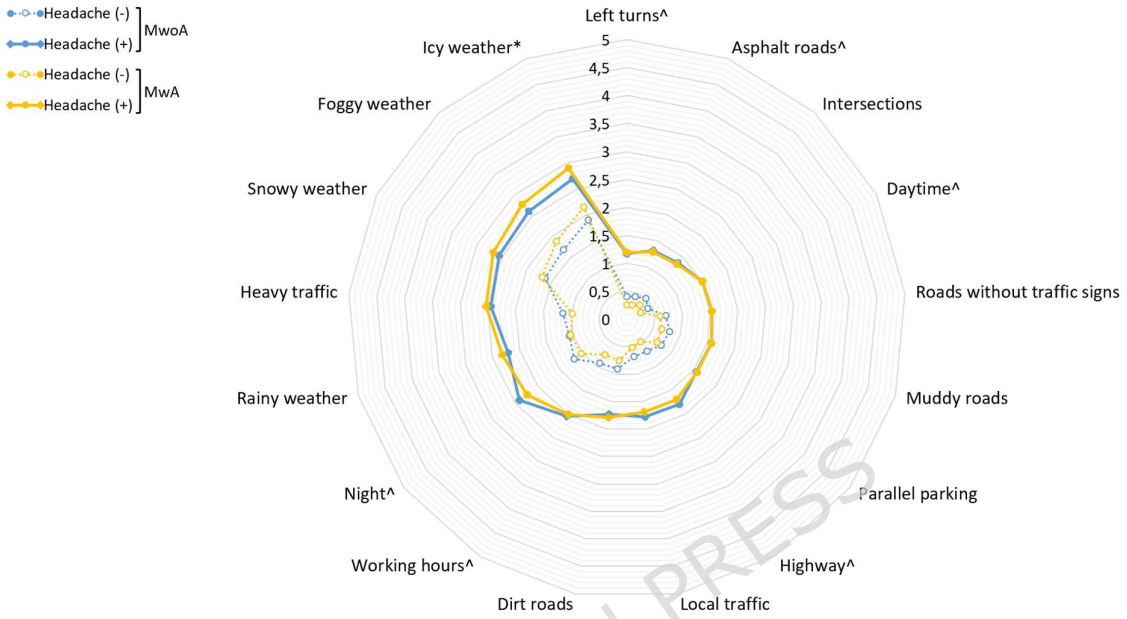


Figure 3: *Spiderweb diagram illustrating drivers' sensitivity who have migraine without aura (MwoA) or migraine with aura (MwA) (n = 315) to road conditions when a headache is present or absent. [When a headache was absent during driving, * shows that the MwA group was more sensitive than the MwoA, and ^ shows that the MwA group was less sensitive than the MwoA. When a headache was present during driving, there was no relationship between the MwoA and MwA groups; however, both groups were more sensitive to road conditions (p < 0.05 in all conditions). The severity score ranges from 0 (no difficulty) to 5 (significant difficulty).]*

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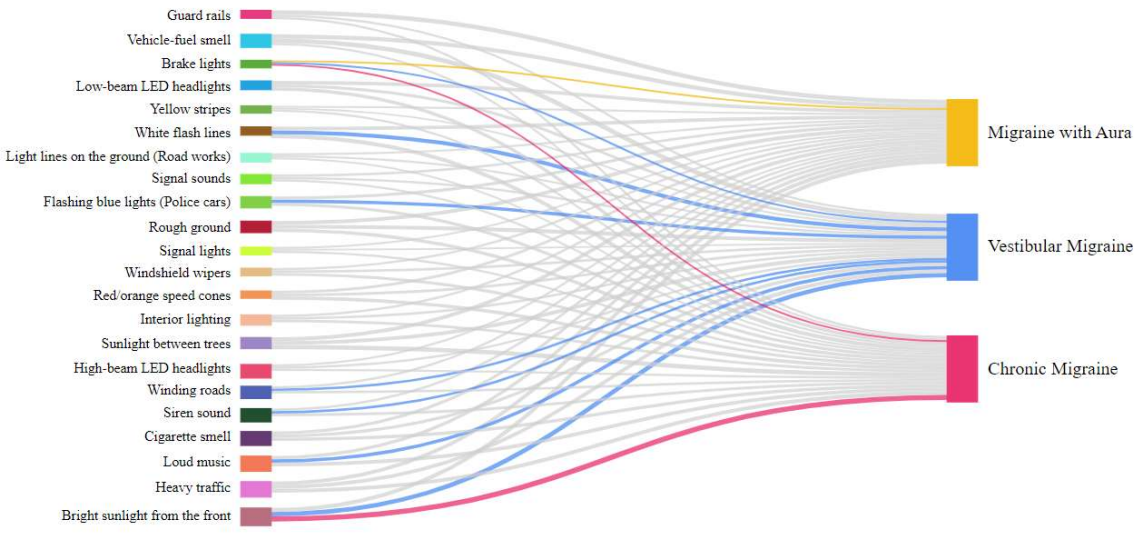


Figure 4: *Sankey diagram illustrating the impact of road conditions in terms of triggering or aggravating headaches across different migraine subtypes. The parameters highlighted in color indicate statistically significant differences between patients with migraine with aura and those without aura, as well as between individuals with vestibular migraine and those without, and between episodic and chronic migraine ($p < 0.05$).*

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Driving Behaviors and Clinical Features in Patients with Vestibular Migraine

The rate of patients who reduced or ceased driving due to persistent postural-perceptual dizziness and/or chronic migraine with paroxysmal vestibular symptoms was 4.7%, compared to 3.8% in those with episodic VM. This difference was statistically significant ($p < 0.001$). There was no significant relationship found between VM and a history of traffic accidents ($p = 0.406$) (see Table 1). Among patients with episodic migraine (EM), the traffic accident rate was significantly lower in those with VM (3.3% vs. 18.8%; $p = 0.029$). Additionally, the accident rate was notably higher in patients with persistent postural-perceptual dizziness and/or chronic migraine with paroxysmal vestibular symptoms compared to those with EM (85.7% vs. 14.3%; $p = 0.010$). However, the mean age of individuals without VM who experienced an accident was lower than that of those who did not have an accident (35.26 years, $p = 0.012$). The clinical characteristics of headaches, their impact on driving, and coping mechanisms for managing headaches were summarized in **Tables 1-3**, respectively. The drivers' sensitivity to road conditions is illustrated in **Figures 4** and **5**.

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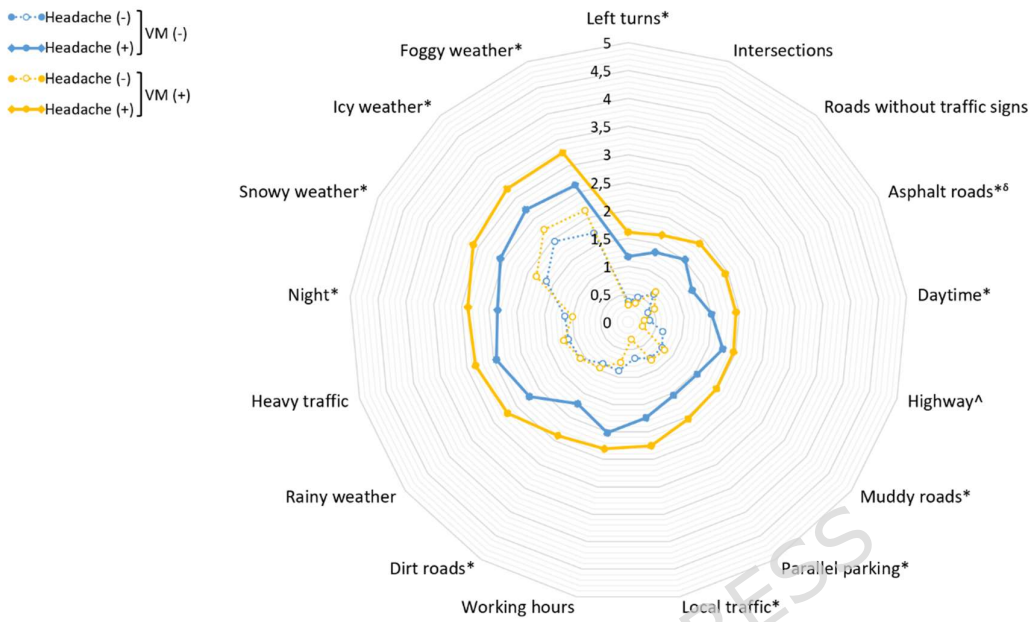


Figure 5: *Spiderweb diagram illustrating drivers' sensitivity who have vestibular migraine (VM) (n = 51) or not, to road conditions when a headache is present or absent [When a headache was absent during driving, ^ shows that VM patients were less sensitive to highway driving (p=0.015) and δ shows that more sensitive to asphalt roads. When a headache was present during driving, * shows that in VM patients, sensitivity to factors such as snowy, icy, and foggy weather, dirt, muddy, or asphalt roads, day/night travel, local traffic, left turns, and parallel parking was significantly increased when a headache was present (all p < 0.05). Additionally, both groups are more sensitive to road conditions during a headache attack (p < 0.05 in all conditions). The severity score ranges from 0 (no difficulty) to 5 (significant difficulty).]*

Driving Behaviors and Clinical Features in Patients with Chronic Migraine

Accident rates were similar between the chronic migraine (CM) group (17.7%) and the episodic migraine (EM) group (17.9%) as shown in Table 1. However, experiencing a headache while driving significantly increased the risk of an accident ($p < 0.001$). Specifically, 96.9% of the accidents involving CM patients occurred while they were experiencing a headache, compared to 77.2% in EM patients. Additionally, the presence of

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aura was identified as a significant factor that increased the accident rate among EM individuals, with rates of 31.1% for those with aura compared to 23.5% for those without (p = 0.039). Nonetheless, there was no significant difference between the EM and CM groups regarding the reduction or cessation of driving due to the presence of aura (p = 0.647 and p = 0.636, respectively). Furthermore, there was no significant increase in accident rates associated with medication-overuse headaches in the CM group. Clinical characteristics, the challenges headaches can pose while driving, and coping mechanisms for dealing with headaches are summarized in **Tables 1** through **3**. Drivers' sensitivity to road conditions is illustrated in **Figures 4** and **6**.

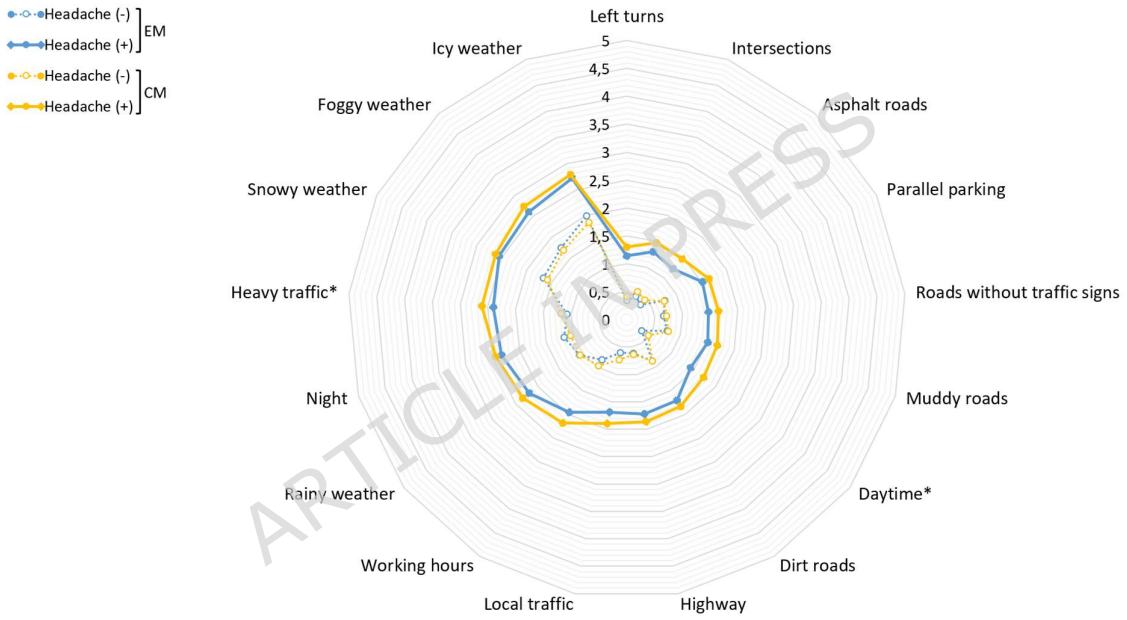


Figure 6: *Spiderweb diagram illustrating drivers' sensitivity who have episodic migraine (EM) or chronic migraine (CM) (n = 383) to road conditions when a headache is present or absent [When a headache is present during driving, * shows that CM patients were more sensitive to heavy traffic and daytime driving (p = 0.049 and p = 0.021, respectively). Additionally, both groups are more sensitive to road conditions during a headache attack (p < 0.05 in all conditions). The severity score ranges from 0 (no difficulty) to 5 (significant difficulty).]*

The associations between migraine subtypes, accompanying symptoms, road conditions, and accidents

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Parameters found to be directly or indirectly related to the accident were modeled using SEM. The direct and mediating effects of the parameters were evaluated and illustrated using **path diagrams**. In the model, migraine characteristics and symptoms were modeled as exogenous latent variables, and their relationships with manifest parameters (Manifest1: Migraine subtypes (MwA, VM, and CM); Manifest2: Accompanying symptoms (E.g., nausea, neck pain)) were evaluated. A statistically significant relationship existed between the common effects of aura and CM ($p<0.05$). All other symptoms accompanying the pain, except for autonomic symptoms, were found to be significantly related to their common effects in the model ($p<0.05$). In the model, the driver's sensitivity to road conditions was represented as an endogenous latent variable to illustrate how external latent variables influenced it, and the relationships between these variables and their apparent parameters (such as heavy traffic) were also modeled. All relationships between driver sensitivity to road conditions and significant variables were statistically significant. Other endogenous variables were driving-related headaches and accidents.

Migraine character positively affected driving-related headaches ($\beta = 0.814$, $p < 0.01$), while it negatively affected driver sensitivity to road conditions ($\beta = -0.867$, $p < 0.01$). In addition, the latent variable symptoms had a positive effect on driving-related headaches ($\beta = 0.092$, $p < 0.01$), while they had a negative effect on driver sensitivity to road conditions ($\beta = -0.064$, $p < 0.05$). Driving-related headaches had a positive effect on driver sensitivity to road conditions ($\beta = 1.202$, $p < 0.01$). Finally, driver sensitivity to road conditions had a positive effect on accidents. Driving-related headaches had no direct significant effect on accidents, but they had a mediating effect on drivers' sensitivity to road conditions **(Figure 7)**.

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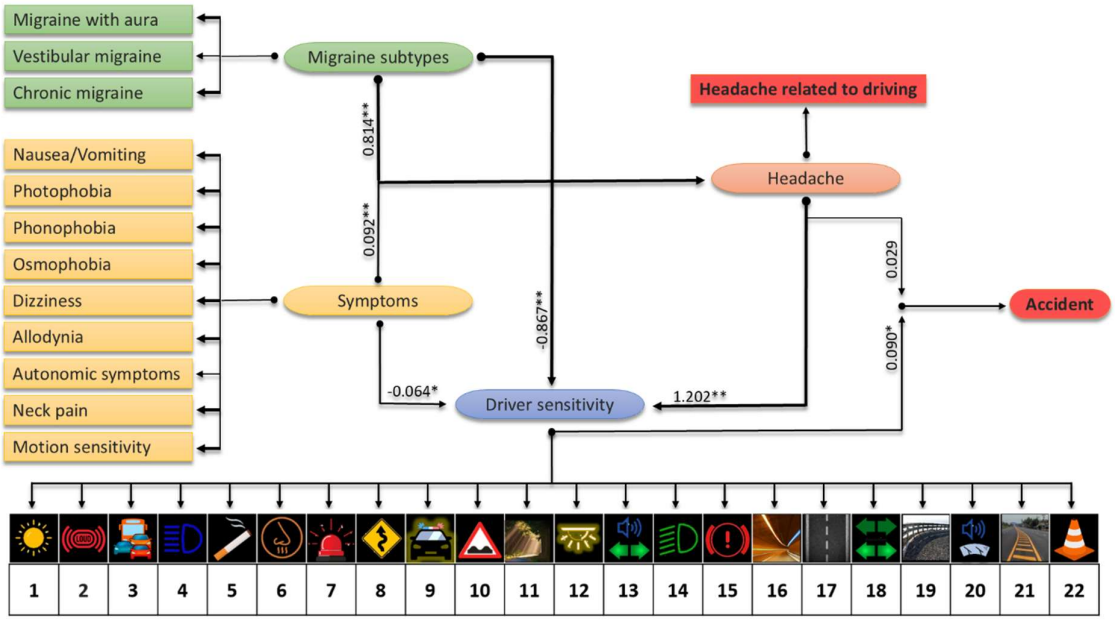


Figure 7: *In the path diagram, the relationships between endogenous and exogenous latent variables were shown using beta coefficients of the model, and their significances were illustrated with single or double stars (*: $p < 0.05$ and **: $p < 0.01$). The significant relationships between manifest and latent variables were indicated with bold arrows. (The road conditions that drivers have sensitivity (All parameters were sorted according to the size of their impact ratio, respectively from left to right): (1) bright sunlight from the front; (2) listening to loud music; (3) heavy traffic; (4) high-beam LED headlights; (5) cigarette smell; (6) vehicle-fuel smell; (7) siren sound; (8) winding roads; (9) flashing blue lights on police cars; (10) roads with rough ground; (11) sunlight setting between rows of trees; (12) interior lighting; (13) signal sounds; (14) low-beam LED headlights; (15) brake lights; (16) light lines close to the ground (road works); (17) very narrow curved white flash lines in the middle of the roads; (18) signal lights; (19) guard rails; (20) sound and sight of windshield wipers; (21) yellow stripes when approaching roundabouts; (22) when passing red/orange speed cones)*

The associations between migraine subtypes, accompanying symptoms, road conditions, HIT-6 scores, and driving cessation

Parameters directly or indirectly related to "driving cessation" were modeled using SEM similar to the above design: (Manifest1: Migraine subtypes (MwA, VM, and CM); Manifest2: Accompanying symptoms (E.g., nausea, neck pain)). All migraine subtypes exhibited

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statistically significant common effects ($p<0.05$). All symptoms except osmophobia were significantly related to their common effects in the model ($p<0.05$). In the model, the driver's sensitivity to road conditions was represented as an internal latent variable, illustrating how external latent variables influence it, and its relationships with its apparent parameters (such as heavy traffic) were also modeled. All relationships between the driver's sensitivity to road conditions and apparent variables were statistically significant. Other endogenous variables were driving-related headaches, HIT-6, and accidents. While migraine character has positive effects on driving-related headache ($\beta = 0.217$, $p < 0.01$) and HIT-6 ($\beta = 3.878$, $p < 0.01$), it has a negative effect on the driver's sensitivity to road conditions ($\beta = -0.365$, $p < 0.01$). The latent variable for the symptoms was not associated with driving-related headaches ($\beta = 0.028$, $p > 0.05$). However, while it negatively affects the HIT-6 ($\beta = -0.999$, $p < 0.05$), it has a positive effect on the sensitivity of drivers to road conditions ($\beta = 0.147$, $p < 0.01$). Driving-related headaches had a positive effect on driver sensitivity to road conditions ($\beta = 1.828$, $p < 0.01$). Finally, driver sensitivity to road conditions and HIT-6 had a positive effect on "driving cessation" ($\beta1 = 0.198$, $p < 0.01$) and ($\beta1 = 0.155$, $p < 0.01$) **(Figure 8)**.

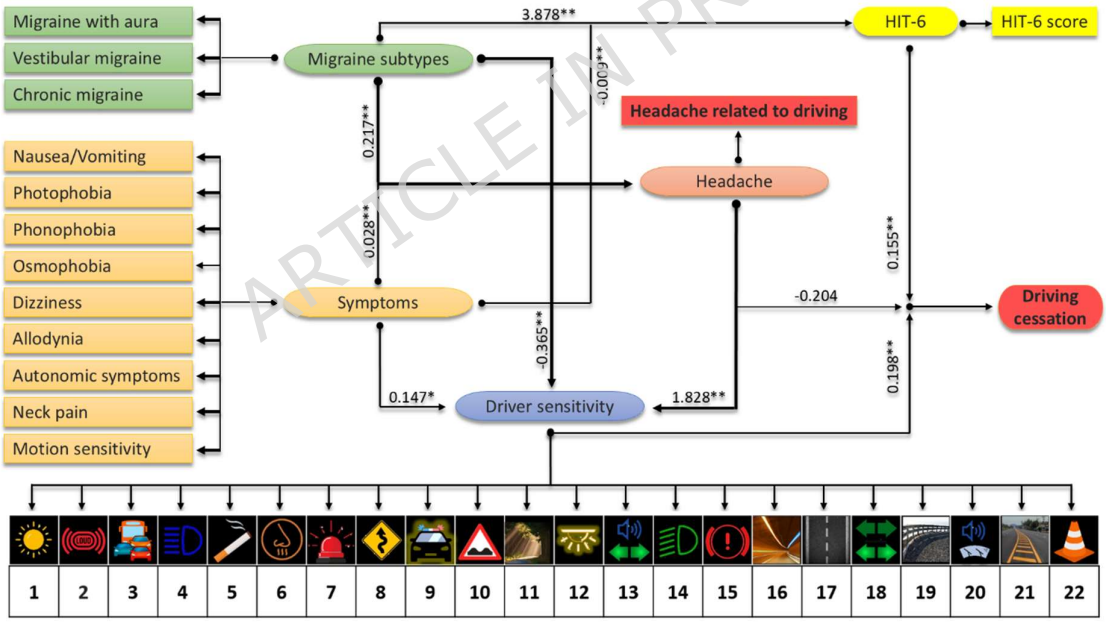


Figure 8: *In the path diagram, the relationships between endogenous and exogenous latent variables were shown using beta coefficients of the model, and their significances were illustrated with single or double stars (*: $p < 0.05$ and **: $p < 0.01$). The significant relationships between manifest and latent variables were indicated with bold arrows. (The road conditions that drivers have sensitivity (All parameters were sorted according to the size of their impact ratio, respectively from left to right): (1) bright sunlight from the front; (2)*

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listening to loud music; (3) heavy traffic; (4) high-beam LED headlights; (5) cigarette smell; (6) vehicle-fuel smell; (7) siren sound; (8) winding roads; (9) flashing blue lights on police cars; (10) roads with rough ground; (11) sunlight setting between rows of trees; (12) interior lighting; (13) signal sounds; (14) low-beam LED headlights; (15) brake lights; (16) light lines close to the ground (road works); (17) very narrow curved white flash lines in the middle of the roads; (18) signal lights; (19) guard rails; (20) sound and sight of windshield wipers; (21) yellow stripes when approaching roundabouts; (22) when passing red/orange speed cones)

DISCUSSION

Our results highlighted that migraine has a remarkable impact on driving; patients with migraine experienced headache in an average of one out of every 10 drives. While 1.7% of the patients ceased driving due to migraine, 9.2% had reduced their driving frequency. Although there were differences in the MwA, VM, and CM subgroups, the results were generally similar, with road conditions causing mild to moderate disability in drivers. The most striking factor was the weather conditions **(Figures 2, 3, 5, and 6)**. Headaches experienced while driving could often cause to factors such as a lapse in attention, feelings of restlessness, and increased irritability among drivers **(Table 2)**. While drivers mostly preferred to use medications to cope with the attack, turning off the music and wearing sunglasses were the other most preferred methods **(Table 3)**.

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Only a handful of studies from different countries provide feedback on the negative effects of migraine on driving [2,20-22]. Although clear scientific evidence is limited, these results reflect personal experiences about the effects of migraine on driving because many symptoms accompanying a migraine attack can directly affect driving skills [23].

Probably secondary to a lack of habituation [24] and problems in processing sensory stimuli [25], individuals with migraine have lower discomfort thresholds for various stimuli such as light, sound, odor, thermal, and mechanical stimulation [26], all of which can be experienced during driving. Visual inputs, which play a crucial role in driving and initiating a migraine attack, are important in this respect [27].

The most prominent light-related factors that can provoke migraine are bright sunlight [28-31]. Sources of flicker that may be encountered while driving are also numerous [32,33]. In our study, bright sunlight from the front was the most common light source that caused or

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increased headaches. This effect intensity was observed most in CM patients, followed by VM and MwA patients **(Figure 4)**. As in the study showing that migraine was triggered by the effect of sunlight in a small sample group, light exposure lasting for minutes can lead to a migraine attack in a short time [34,35]. Greater sensitivity to glare, flicker, contrast patterns, fluorescent lights, road markings, and colors was reported in the MwA group than in the MwoA group [36]. No differences were found between the MwA and MwoA groups in our study; this discrepancy in the results may be due to the methodology of the previous study. In one study, drivers rated white lights around headlights and red brake lights as distracting or problematic, and headaches occurred more frequently at night [33]. However, the effect of the red brake lights was less pronounced in our study than that of the headlights. In contrast, a study by Salvania et al. found that drivers rated the red brake lights as more dazzling than the white lights surrounding the headlights [33]. This may be due to the intermittent but repeated exposure caused by the driver repeatedly pressing and releasing the brakes while driving. In the same study, glare was the most frequently reported problem symptom after LED light exposure, followed by blindness or visual impairment, blurring, and double vision. Another feature of the latter study is that it suggests road lighting and warning signs, in addition to vehicle lighting, may be disturbing by causing intermittent and repetitive warnings [33]. Indeed, our study showed that road conditions lead to neglected and low-effect results in individuals with migraines **(Figure 4)**.

Prolonged driving may lead to direct or indirect cumulative perceptual and cognitive problems, such as distraction, irritation, loss of concentration, and avoidance behaviors, which can impact driving performance [33]. Our study found that headaches while driving primarily cause decreased attention in drivers with migraine **(Table 2)**. Therefore, to mitigate the risks that may arise, vehicle and road lighting should be balanced to provide optimal visibility while minimizing the impact on the driver.

Consistent with the literature, motion sickness was detected more in patients with VM than in those without it in this study. Motion sensitivity stands out as a prominent feature of migraine, especially in patients with VM [37]. Previous studies examining motion sickness triggered by activities such as reading in vehicles have found that this sensitivity is 4.3 times more specific in individuals with VM compared to those with benign paroxysmal positional vertigo [38]. Vertigo symptoms can lead to impaired motion perception and spatial orientation, as well as sudden falls, which can affect the ability to operate a motor vehicle safely [39]. Individuals

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with impaired vestibular systems had fourfold more driving difficulties in a study [40]. In our study, patients with VM were significantly more sensitive to all road conditions in the presence of a headache. Vuralli et al. showed that visual motion, postural motion, and a high spatial frequency environment are frequent triggers in VM patients [12]. Migraineurs, especially those with comorbid motion sickness, experience significantly more severe headaches, nausea, imbalance, and even hospitalizations following caloric vestibular testing, likely reflecting maladaptive cortical responses to vestibular stimulation [41]. This exaggerated sensory reactivity may explain the increased driving-related discomfort and accident risk observed in the VM subgroup. In the study by Cohen et al., people with vestibular disorders were aware that their driving performance was not optimal, and they drove less [40].

In the OVERCOME study, which examined 5,485 patients with migraine and a valid driver's license, the rate of not driving increased in correlation with the intensity of the headache [13], a finding similar to our results. Chronic migraineurs reported more visual discomfort in driving and looking at bright screens compared to controls [42]. The increased light sensitivity can explain the relationship with sunlight.

In a study conducted among healthy workers in Italy, headache was the most common symptom after odor exposure (7.3%) [43]. In our study, the odor sources that caused or exacerbated headaches in drivers with migraines were cigarette odor and vehicle-fuel smell **(Figure 4)**. On the other hand, sensitivity to odor increased in the presence of a headache in all groups **(Figures 2, 3, 5, and 6)**.

During a migraine attack, neck or occipital pain may accompany the headache and is observed at the onset of the attack in 46.8% of physical activities [44]. Neck pain has the potential to restrict head movement while driving. Activities that can cause neck pain and require intense visual focus, such as reading and driving, were found to be associated with both more frequent pain and more serious deterioration in the quality of life in individuals with headaches [45]. In our study, neck pain was reported more in CM drivers **(Table 1)**. Similarly, pain severity and HIT-6 scores were higher in this group **(Table 1)**; headaches caused more significant restlessness, irritability, impairment in quick decision-making, and visual impairment in drivers **(Table 2)**.

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Of the drivers, 18.1% had been involved in at least one accident in the past year. A study in the United Arab Emirates (UAE) done in the emergency room found that 61.3% of migraineurs had been involved in a previous accident, and 53.7% had suffered a serious injury [46]. In another study assessing migraineurs with sleep disorders, the rate of crashes and near-crashes was 11.21% [47]. Young drivers have been associated with inadequate safety maneuvers and higher severity crash outcomes in crashes or crash risk situations [47]. Engagement in distractions was highest among young drivers and lowest among middle-aged drivers [48]. In general, young drivers—especially males—tend to overestimate their driving skills. They were also observed to be more willing to underestimate the risk of an accident and to exhibit behaviors that they know are risky [49,50]. In our study, individuals over 65 were not included to exclude age-related confounding factors. The average age of those who had an accident was lower, consistent with the literature, and motion sickness increased the risk. Notably, in our large study, visual aura was associated with an increased accident rate in patients with EM. At the same time, headaches experienced during driving were also associated with accidents, and this association was more pronounced in patients with CM. This relationship was not direct; it was an indirect effect through the sensitivity of drivers to road conditions. Again, the presence of persistent postural-perceptual dizziness and/or chronic migraine with paroxysmal vestibular symptoms increased the risk of accidents.

Remarkably, we found that 1.7% of individuals with migraine ceased driving due to headaches, and 9.2% reduced driving. Drivers with CM had higher rates of both reducing and ceasing driving, which is understandable. One in three who reduced or ceased driving reported experiencing motion sickness while driving. These patients were advised by their doctors not to drive [40]. The driving competence of individuals with migraine should be assessed. However, this assessment should consider the individual variable nature of the disease.

Patient-based studies in the USA suggest that the presence of vestibular disorders in migraine patients alone does not warrant suspension of the driver's license and that regulations should be restructured to reflect physician-patient collaboration [51]. Similarly, it is emphasized that common standards should be established in Europe, considering the impact on quality of life and occupational functioning [52]. Since individuals with migraine are generally aware of the symptoms while driving, they avoid driving before an attack, and during an attack, they actively tend to stop the vehicle safely.

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Individuals with migraine have a lower tolerance to environmental sensory stimuli compared to healthy controls, and this often results in avoidance behaviors [53,54]. In our study, drivers with migraine developed various individual coping strategies during attacks. However, 17.7% of the participants reported that they had continued driving without taking any precautions.
The most common coping method was the use of analgesics or specific attack medications (e.g., triptans) by 59% **(Table 3)**. It is thought that individual experiences or physician recommendations shape this preference. Because it is known that early use of triptans provides better attack control and significantly improves patient satisfaction [55].

The second most common strategy in our study was turning off the music volume, which was employed by 51.9% of participants. This behavior was observed significantly more frequently in individuals with VM. In line with previous studies, it is also known that sensitivity to light, sound, odor, and thermal or mechanical stimuli is higher in individuals with migraine [26]. These findings necessitate developing individualized management approaches to sensory stimulation during driving in individuals with migraine.

To cope with light sensitivity, 47.7% of our participants tried wearing sunglasses; this rate was higher in MwA **(Table 3)**. In this regard, polarized sunglasses and windshield sun visors may be recommended to reduce photic triggers. It is essential for public health that other drivers consider this sensitivity and use high-beam LED headlights only under necessary conditions. Additionally, it has been reported that "Blue Cut for Night" glasses, developed to reduce photic sensitivity, effectively reduce nighttime headaches in individuals with migraine [56]. In the design of vehicle and road lighting systems, light distribution should be provided in a spectrum and intensity that will not trigger excessive sensory stimulation in individuals with migraine while continuing to provide safe vision. In this direction, a balance should be established between lighting engineering and clinical neurological sensitivities. In the event of a migraine attack that may develop while driving, it is essential to have a safe area where driving can be interrupted quickly and easily accessible. Equipping vehicles with dark, quiet, well-ventilated compartments and isolating them from external stimuli, particularly in situations that may trigger migraine attacks, can help patients manage their migraine symptoms more effectively.

A detailed scientific investigation of all the coping strategies listed in our research and the development of specific approaches to ensure that individuals with migraine can drive safely

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without missing out on life will only be possible through increased awareness and further research. Our study represents an important step in exploring coping strategies in this context.

CONCLUSIONS

These findings indicate that migraine should be considered not only as a painful syndrome but also as a neurosensory disorder affecting complex cognitive and sensorimotor activities, such as driving. These effects can limit individuals' independence and social participation in daily life; they also constitute a public risk area, albeit minimal, in terms of traffic safety. Therefore, the driving competence of individuals with migraine should be assessed and improved based on their personal symptom profile and neurological evaluation. Mapping the functional areas affecting driving performance according to migraine subtypes can be guiding for both health professionals and regulatory authorities.

Our results are a novel contribution to the intersection between headache research and traffic safety. The findings provide a scientific basis that can be used in public awareness studies and future management developments.

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Key Findings

- A total of 70% of drivers with migraine have experienced a headache while driving at least once in their lives and have had an attack in an average of 13% of their drives.
- The most frequently reported symptoms during a headache are decreased attention, restlessness, and irritability.
- Bright sunlight coming from the opposite direction, heavy traffic, and listening to loud music while driving are among the most common environmental factors that trigger migraine.
- Pain severity is higher in individuals with MwA, VM, and CM; sensitivity to environmental factors, especially weather conditions, is significantly higher, becoming more evident in the presence of a headache.
- Drivers with migraine mostly try to cope with headaches with strategies such as using analgesics/specific attack medications, turning off the music, and wearing sunglasses.
- A total of 17.7% of drivers with migraine did not take any precautions to cope with the pain during an attack; this situation reveals the need to increase awareness.
- Only 1.7% of individuals with migraine stopped driving due to migraine, while 9.2% reduced their driving frequency.

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• Individuals with migraine should be aware of their symptoms in advance and develop safe driving behavior.
• An increased accident rate in individuals experiencing headaches while driving was found to be associated with visual aura, vestibular migraine, and chronic migraine.

Limitations

• Since the study was conducted in a hospital setting, and there was no healthy control group, the results may not be fully generalizable to the general population.
• Migraine symptoms and driving experiences are based on self-reports from participants. This may limit data accuracy due to recall bias and individual differences in perception.
• Another limitation of this study was the lack of test-retest reliability or a Turkish version of the "Driving Habit Questionnaire". There is a need for standardized tests about this issue in different languages.
• Objective neurological or simulator-based measurements on driving performance and migraine effects are needed. Thus, our study design was unable to fully demonstrate the real-time effects on certain cognitive and motor functions.
• The medications and treatment methods used by participants, as well as comorbid diseases, may have different effects on driving performance. However, this study design has limitations in controlling or isolating the effects of these parameters.
• External factors such as traffic conditions, vehicle type, road conditions, and stress factors originating from the social environment were not addressed in detail in the study.

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Abbreviations

β : Beta coefficients

CM : Chronic migraine

EM : Episodic migraine

HIT-6 : Headache Impact Test-6

ICHD-3 : The International Classification of Headache Disorders, 3rd edition

MwA : Migraine with aura

MwoA : Migraine without aura

LED : Light-emitting diode

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SEM : Structural Equation Modeling

TTH : Tension-type headache

UAE : The United Arab Emirates

VM : Vestibular migraine

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Ethics declarations

Ethics approval and consent to participate

The study was formally approved by the Medical Research Ethics Committee (ATADEK - Decision No: 2024-5/204). Researchers secured online informed consent forms from all participating patients according to the Declaration of Helsinki, which outlines ethical principles for medical research involving human subjects.

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Consent for publication

Not applicable.

Data availability

The datasets analyzed in this study are available from the corresponding author upon reasonable request.

Competing interests

The authors declare no conflicts of interest related to the materials, methods, or findings of this study.

Funding

Not applicable.

Authors' contributions

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Acknowledgements

We thank the Global Migraine and Pain Society for study design and network support.

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Supplementary File Information

Supplementary files 1, 2, 3, and 4.

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Table 1: Drivers' demographic features, headache characteristics, results related to driving, and HIT-6 scores, according to the migraine subtypes

		Total (Drivers)	Migraine without aura	Migraine with aura	p-value	Vestibular migraine (-)	Vest migra
Female	n (%)	859 (64.4)	644 (63.3)	215 (68.3)	0.106	822 (64.1)	37 (
Age	Mean ± SD	36.75±9.53	36.67±9.63	37.03±9.20	0.551	36.66±9.49	38.94
Headache frequency (in the last 3 months)		8.82±7.25	8.53±7.12	6.92±6.08	**<0.001**	8.12±6.96	8.90
Lifetime migraine duration		11.56±9.2	11.37±9.31	12.17±8.86	0.18	11.52±9.15	12.71
VNS		7.56±1.55	7.45±1.59	7.89±1.36	**<0.001**	7.53±1.55	8.18
Accompanying symptoms							
Nausea-vomiting		972 (72.9)	717 (70.4)	255 (81)	**<0.001**	929 (72.5)	43 (
Photophobia		1123 (84.2)	852 (83.7)	271 (86)	0.32	1083 (84.5)	40 (
Phonophobia	n (%)	999 (74.9)	747 (73.4)	252 (80)	**0.018**	963 (75.1)	36 (
Osmophobia		453 (34)	320 (31.4)	133 (42.2)	**<0.001**	429 (33.5)	24 (
Dizziness		406 (30.5)	294 (28.9)	112 (35.6)	**0.024**	362 (28.2)	44 (

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Allodynia		300 (22.5)	230 (22.6)	70 (22.2)	0.89	282 (22)	18 (
Autonomic findings		158 (11.9)	107 (10.5)	51 (16.2)	**0.006**	145 (11.3)	13 (
Motion sensitivity		682 (51.2)	532 (52.3)	150 (47.6)	0.15	649 (50.6)	33 (
Neck pain		665 (49.9)	521 (51.2)	144 (45.7)	0.09	634 (49.5)	31 (
Results related to driving							
Drivers		1333 (100)	960 (48.1)	299 (56.7)	**0.008**	1213 (50)	46 (
Drivers who quitted driving		74 (5.6)	58 (2.9)	16 (3)	0.675	69 (2.8)	5 (
Reducing/quitting driving due to migraine		144 (10.8)	111 (10.9)	33 (10.5)	0.831	138 (10.8)	6 (1
Drivers who reduced their driving due to migraine	n (%)	122 (9.2)	92 (9)	30 (9.5)	0.788	117 (9.1)	5 (
Drivers who quitted driving due to migraine		22 (1.7)	19 (1.9)	3 (1)	0.279	21 (1.6)	1
Drivers who had migraine headache experience while driving		941 (70.6)	717 (70.5)	224 (71.1)	0.836	900 (70.3)	41 (
Accident ratio		231 (18.1%)	172 (17.6%)	59 (19.7%)	0.407	224 (18.3%)	7 (13
Driving frequency per week in the last month (day)		4.86±2.26	4.78±2.27	5.12±2.18	**0.016**	4.85±2.25	5.12
Driving frequency in the last month (times)		19.1±10.56	18.70±10.6	20.37±10.31	**0.009**	19.02±10.54	20.98
Percentage of headaches while driving in the last month	Mean ± SD	13.02±20.54	12.85±20.13	13.54±21.81	0.639	12.86±20.47	16.93
Duration of headache that occurs while driving		3.36±6.99	3.26±6.91	3.67±7.24	0.054	3.31±7.00	4.56
VNS of headache that occurs while driving		6.02±2.3	5.91±2.31	6.4±2.21	**0.003**	5.98±2.3	7.07
Headache Impact Test-6 score		62.22±7.09	62.65±7.17	63.65±7.18	**0.003**	62.75±7.18	65.5

VNS: *Visual Numeric Scale;* ***SD:*** *Standard Deviation*

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Table 2: Non-headache symptoms during migraine while driving

	Total (Drivers)	**Migraine without aura**	**Migraine with aura**	**p-value**	**Vestibular migraine (-)**	**Vestibular migraine (+)**	**p-value**	**Episodic migraine**	**Chronic migraine**	**p-value**
	n (%)	**n (%)**	**n (%)**		**n (%)**	**n (%)**		**n (%)**	**n (%)**	
Decreased attention	1007 (69)	665 (65.3)	219 (69.5)	0.168	843 (65.8)	41 (80.4)	**0.03**	637 (67.1)	247 (64.5)	0.371
Restlessness	963 (66)	632 (62.1)	185 (58.7)	0.286	783 (61.1)	34 (66.7)	0.422	566 (59.6)	251 (65.5)	**0.043**
Irritability	821 (56)	534 (52.5)	166 (52.7)	0.94	668 (52.1)	32 (62.7)	0.136	467 (49.2)	233 (60.8)	**<0.001**
Decreased attention to road conditions	618 (42)	428 (42)	142 (45.1)	0.341	540 (42.1)	30 (58.8)	**0.018**	408 (42.9)	162 (42.3)	0.828

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Increased anxiety/concern about having an accident	455 (31)	289 (28.4)	102 (32.4)	0.174	369 (28.8)	22 (43.1)	**0.027**	276 (29.1)	115 (30)	0.724
Weakened reflexes (Decreased/impaired ability to make quick maneuvers)	419 (29)	273 (26.8)	113 (35.9)	**0.002**	362 (28.2)	24 (47.1)	**0.004**	272 (28.6)	114 (29.8)	0.68
Impairment in quick decision-making	416 (28)	274 (26.9)	103 (32.7)	**0.046**	356 (27.8)	21 (41.2)	**0.037**	254 (26.7)	123 (32.1)	**0.049**
Visual impairment	372 (25)	209 (20.5)	118 (37.5)	**<0.001**	302 (23.6)	25 (49)	**<0.001**	218 (22.9)	109 (28.5)	**0.034**
Poor lane tracking	299 (20)	201 (19.7)	77 (24.4)	0.073	262 (20.4)	16 (31.4)	0.059	197 (20.7)	81 (21.1)	0.867

Table 3: According to the migraine subtypes, drivers' coping strategies through migraine attacks while driving

	Total	**Migraine without aura**	**Migraine with aura**	**p-value**	**Vestibular migraine (-)**	**Vestibular migraine (+)**	**p-value**	**Episodic migraine**	**Chronic migraine**	**p-value**
	n (%)	**n (%)**	**n (%)**		**n (%)**	**n (%)**		**n (%)**	**n (%)**	
Using painkillers/attack medication	724 (58.8)	559 (59.2)	165 (57.5)	0.616	691 (58.4)	33 (68.8)	0.152	496 (57.1)	228 (62.8)	0.062
Turning off music	640 (51.9)	485 (51.3)	155 (54)	0.425	607 (51.3)	33 (68.8)	**0.017**	451 (51.9)	189 (52.1)	0.957
Using sunglasses	588 (47.7)	434 (45.9)	154 (53.7)	**0.022**	563 (47.6)	25 (52.1)	0.538	408 (47)	180 (49.6)	0.398
Opening the windows of the vehicle to ventilate	542 (44)	407 (43.1)	135 (47)	0.235	514 (43.4)	28 (58.3)	**0.041**	377 (43.4)	165 (45.5)	0.504
Consuming fluids	467 (37.9)	358 (37.9)	109 (38)	0.977	447 (37.8)	20 (41.7)	0.584	319 (36.7)	148 (40.8)	0.18
Reducing driving speed	462 (37.5)	342 (36.2)	120 (41.8)	0.085	437 (36.9)	25 (52.1)	**0.033**	331 (38.1)	131 (36.1)	0.508
Asking another driver to continue driving if there is one next to me	294 (23.9)	197 (20.8)	97 (33.8)	**<0.001**	270 (22.8)	24 (50)	**<0.001**	208 (23.9)	86 (23.7)	0.927
Using a sun visor placed on the windshield inside the vehicle	247 (20)	171 (18.1)	76 (26.5)	**0.002**	231 (19.5)	16 (33.3)	**0.019**	178 (20.5)	69 (19)	0.556
Avoiding night driving due to the greater effect of vehicle headlights	174 (14.1)	121 (12.8)	53 (18.5)	**0.016**	163 (13.8)	11 (22.9)	0.074	120 (13.8)	54 (14.9)	0.624
Trying not to drive in crowded areas	150 (12.2)	108 (11.4)	42 (14.6)	0.146	136 (11.5)	14 (29.2)	**<0.001**	105 (12.1)	45 (12.4)	0.878
Taking a break from driving	131	83	48	**<0.00**	117	14	**<0.00**	93	38	0.903

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and waiting for the attack to pass	(10.6)	(8.8)	(16.7)	**1**	(9.9)	(29.2)	**1**	(10.7)	(10.5)	
Continuing driving without doing anything*	218 (17.7)	175 (18.5)	43 (15)	0.169	213 (18)	5 (10.4)	0.178	152 (17.5)	66 (18.2)	0.772

***** *indicates that individuals do not take any action to cope with their headache while driving.*

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