Received: 23 August 2021 | Accepted: 24 March 2022
DOI: 10.1111/head.14309

RESEARCH SUBMISSIONS

Migraine and balance impairment: Influence of subdiagnosis, otoneurological function, falls, and psychosocial factors

Gabriela F. Carvalho PT, PhD[1,2] | Kerstin Luedtke PT, PhD[2,3] | Carina F. Pinheiro PT, PhD[1] | Renato Moraes PhD[4] | Tenysson W. Lemos PhD[1] | Camila G. Carneiro MD, PhD[5] | Marcelo E. Bigal MD, PhD[6] | Fabiola Dach MD, PhD[7] | Debora Bevilaqua-Grossi PT, PhD[1]

[1]Department of Health Sciences, Ribeirão Preto Medical School, University of São Paulo, Ribeirão Preto, Brazil

[2]Institut für Gesundheitswissenschaften, Studiengang Physiotherapie, Pain and Exercise Research Luebeck (P.E.R.L), Universität zu Lübeck, Lübeck, Germany

[3]Laboratory of Pain Research, The Jerzy Kukuczka Academy of Physical Education, Katowice, Poland

[4]School of Physical Education and Sport of Ribeirão Preto, University of São Paulo, Ribeirão Preto, Brazil

[5]Department of Ophthalmology, Otolaryngology and Head & Neck Surgery, Ribeirão Preto Medical School, University of São Paulo, Ribeirão Preto, Brazil

[6]Ventus Therapeutics, Montreal, Quebec, Canada

[7]Department of Neurosciences and Behavioral Sciences, Ribeirão Preto Medical School, University of São Paulo, Ribeirão Preto, Brazil

Correspondence
Gabriela F. Carvalho, Department of Physiotherapy, Institute of Health Sciences, University of Luebeck, Ratzeburger Allee 160, 23562 Luebeck, Germany.
Email: gabriela.fisioterapia@gmail.com

Funding information
FAPESP Foundation, grants 2015/18031-5 and 2017/07482-1

Abstract

Objective: To assess the balance sensory organization among patients with migraine, considering the influence of migraine subdiagnosis, otoneurological function, falls, and psychosocial factors.

Background: Migraine has been associated with vestibular symptoms and balance dysfunction; however, neither comprehensive balance assessment nor associated factors for greater impairment have been addressed thus far.

Methods: Patients from a tertiary headache clinic with a diagnosis of episodic migraine with aura (MWA), without aura (MWoA), and chronic migraine (CM) were included for this cross-sectional study (30 patients per group). Thirty headache-free controls (CG) were recruited. Participants underwent a comprehensive evaluation protocol, including the Sensory Organization Test (SOT) and otoneurological examination. Questionnaires about fear of falls, dizziness disability, and kinesiophobia were administered.

Results: All migraine groups presented lower composite SOT scores than controls (CG: 82.4 [95% confidence interval (CI): 79.5–85.3], MWoA: 76.5 [95% CI: 73.6–79.3], MWA: 66.5 [95% CI: 63.6–69.3], CM: 69.1 [95% CI: 66.3–72.0]; $p < 0.0001$). Compared to controls and to MWoA, MWA and CM groups exhibited greater vestibular (CG: 75.9 [95% CI: 71.3–80.4], MWoA: 67.3 [95% CI: 62.7–71.8], MWA: 55.7 [95% CI: 51.2–60.3], CM: 58.4 [95% CI: 53.8–63.0]; $p < 0.0001$) and visual functional impairment (CG: 89.6 [95% CI: 84.2–94.9], MWoA: 83.2 [95% CI: 77.9–88.6], MWA: 68.6 [95% CI: 63.3–74.0], CM: 71.9 [95% CI: 66.5–77.2], $p < 0.0001$). Fall events during the assessment were documented more often among patients with migraine (CG: 0.0, interquartile range [IQR], 0.0, 0.0); MWoA: 1.0 [IQR: 1.0, 1.0], MWA: 2.0 [IQR: 1.8, 4.3], CM: 1.0 [IQR: 1.0, 2.0]; $p = 0.001$). The SOT scores correlated with fear of falls ($r = -0.44$),

Abbreviations: BMI, body mass index; CI, confidence interval; CM, chronic migraine; CoP, center of pressure; DHI, Dizziness Handicap Inventory; ENG, electronystagmography; FES-I, Falls Efficacy Scale–International; ICHD-3, International Classification of Headache Disorders, 3rd edition; MWA, migraine with aura; MWoA, migraine without aura; PHQ-9, Patient Health Questionnaire; SOT, Sensory Organization Test.

dizziness disability ($r = -0.37$), kinesiophobia ($r = -0.38$), and migraine frequency ($r = -0.38$). There was no significant influence of the vestibular migraine diagnosis in the study outcomes when used as a covariate in the analysis (composite score [$F = 3.33$, $p = 0.070$], visual score [$F = 2.11$, $p = 0.149$], vestibular score [$F = 1.88$, $p = 0.172$], somatosensory score [$F = 0.00$, $p = 0.993$]).

Conclusions: Aura and greater migraine frequency were related to falls and balance impairment with sensory input manipulation, although no otoneurological alterations were detected. The diagnosis of vestibular migraine does not influence the balance performance. The vestibular/visual systems should be considered in the clinical examination and treatment of patients with migraine.

KEYWORDS
aura, computerized dynamic posturography, postural balance, primary headache disorders, vestibular function tests, vestibular migraine

INTRODUCTION

Migraine is often accompanied by vestibular symptoms and balance disorders.[1-3] Recent studies have highlighted the influence of aura and frequent migraine attacks on motion perception, including a higher likelihood of vestibular symptoms, falls, and increased postural sway.[4-6] Other studies have shown impaired postural control among patients classified with vestibular migraine, which is described in the International Classification of Headache Disorders 3rd edition (ICHD-3) Appendix as the presence of vestibular symptoms in association with migraine features.[3,7-10] However, otoneurological and balance dysfunction can also be prevalent, even in patients with migraine not reporting vestibular symptoms.[11-15] Therefore, it is not clear whether postural control alterations are related to headache subtypes or the presence of vestibular complaints and dysfunction.

The reference method to assess balance impairment is the Sensory Organization Test (SOT), which is performed in dynamic, computerized posturography equipment;[16-20] so far, to the best of our knowledge, this test has not been used in migraine research. This test quantifies and distinguishes the functional contribution of visual, vestibular, and somatosensory inputs on postural sway,[16] assessing sensory-conflict causes and fall risk.[17-19,21,22]

Because it can contribute to understanding the sensory systems conflict in migraine, this study aimed to evaluate balance in the population with migraine and headache-free controls using the SOT while also considering otoneurological examination, different disease classifications, and psychosocial aspects. Compared to controls, we hypothesize that patients with migraine present lower thresholds in the perception of vestibular, visual, and somatosensory input. According to the previous literature,[4-6,13] we expect that the subtypes of aura and chronic migraine are associated with greater balance impairment. Furthermore, lower SOT scores may correlate with greater perceived dizziness disability, higher fear of falls, and fear of movement.

METHODS

Participants

We recruited women aged between 18 and 55 years with and without migraine to participate in this cross-sectional study between January and November of 2018. We screened patients with migraine in a tertiary headache clinic at the Ribeirao Preto Clinics Hospital in Brazil. Patients were diagnosed with migraine with and without aura or chronic migraine by headache experts according to the ICHD-3.[10] Consecutive headache-free controls were recruited among patients' family and friends and in the local community. We included patients who had at least 2 years of migraine diagnosis with a minimum of three migraine attacks within the 3 months prior to study participation. Patients diagnosed with migraine with and without aura with a maximum of 12 headache days per month were considered, while patients with chronic migraine had a minimum of 15 headache days within a month. Patients with aura were included if they presented typical aura. Exclusion criteria for all groups encompassed: (1) systemic diseases such as fibromyalgia, diabetes, rheumatoid disease, or uncontrolled hypertension; (2) past or current diagnosis of acute vestibular diseases, such as labyrinthitis or neuritis; (3) concomitant headache diagnosis; (4) abnormal neurological examination results; (5) body mass index (BMI) greater than 30; and (6) any associated musculoskeletal or head injury, other neurologic disorder, or chronic pain. In addition, any report of primary headache or any secondary headache with occurrence greater than two times within the previous 6 months were considered exclusion criteria for the control group. Furthermore, patients with a migraine attack during the assessment had their appointment rescheduled. The local ethics committee approved the study procedures (HCRP process number: 15572/2016). The researcher explained and clarified the procedures to all participants before they signed written informed consent, following the Declaration of Helsinki.

Among 166 potential participants, we excluded 46 due to the presence of vestibular diseases (n = 6), concomitant headaches (n = 6), BMI >30 (n = 3), musculoskeletal injury (n = 6), and no availability to attend the appointment (n = 25). The remaining 120 participants were distributed equally to the following groups: control group (n = 30), migraine without aura (MWoA; n = 30), migraine with aura (MWA; n = 30), and chronic migraine (CM) group (n = 30).

Experimental procedure

Participants who fulfilled the eligibility criteria after the initial screening had an appointment scheduled with an assessor blinded to the patient's diagnosis. All underwent computerized dynamic posturography (EquiTest, NeuroCom) and electronystagmography (ENG). The EquiTest is composed of two force plates (45.75 × 45.75 cm) surrounded by the sway-referenced visual environment (Figure 1). The SOT is validated to assess postural sway,[20,23,24] has excellent test–retest reliability,[18,23,25] and a minimal detectable change of 8 points[26] with high sensitivity to detect balance abnormalities and fall risk.[17,21,22,27] The SOT protocol is composed of six assessment conditions, described as follows: (1) fixed surface and eyes opened: all sensory inputs available; (2) fixed surface and eyes closed: absence of visual input; (3) fixed surface and sway-referenced visual surrounding with eyes opened: inaccurate visual input; (4) sway-referenced surface and eyes opened: inaccurate somatosensory input; (5) sway-referenced surface and eyes closed: without visual input and inaccurate somatosensory input; and (6) sway-referenced surface and sway-referenced visual surrounding with eyes opened: inaccurate somatosensory and visual inputs.

FIGURE 1 Test position in the NeuroCom EquiTest equipment. *Published with the participant's permission[Color figure can be viewed at wileyonlinelibrary.com]

All conditions were assessed three times with 20-s duration each. Patients were upright and secured by an overhead harness to prevent falling but without limiting sway. According to the manufacturer's instructions, patients had bare feet, with a standardized distance between the feet.[28] The main outcomes are the scores of the visual, vestibular, and somatosensory systems, and a composite score. These scores were calculated from the six conditions with an interval output ranging from 0 to 100, with higher scores indicating better body stability.[16,28] Beyond the standard analysis provided by the EquiTest software, we exported the raw data of the center of pressure (CoP) obtained by the force plates for each condition of the SOT. These data allowed us to compute the CoP's sway area (measured in squared centimeters and using 90% of the displacement ellipse) and sway speed (in centimeters per second) using a MATLAB 2019a code.[29] Furthermore, fall events during the trials were recorded. A fall was considered when patients supported their weight on the harness owing to not being able to recover their balance during the trial.

For the ENG assessment, three electrodes were placed in the periorbital region to detect the electromyographic activity of the periorbital muscles. All participants performed three assessment protocols: oculomotor evaluation, rotatory chair test (pendular sinusoidal), and caloric test. The oculomotor testing evaluated the presence of nystagmus with eyes opened and closed, presence of gaze nystagmus, and/or asymmetrical gain in the optokinetic test (i.e., differences between sides >17%). The rotatory chair testing (low to mid frequency function) was performed through sinusoidal harmonic downward oscillation with participants tilted by 30° forward to optimally align the horizontal semicircular horizontal canals with the horizontal space plane and their eyes closed. To measure the vestibulo-ocular reflex, eye movements were recorded using ENG. The maximum angular velocity was set at 50°/s, and a percentage gain greater than 30 was considered abnormal. The caloric testing (low frequency) was the final test, and it was performed with the patient in supine position with a head incline of 30°. Each ear was irrigated with a constant flow of air at temperatures of 50 and 24°C for 60 s.[30] Nystagmus was recorded using ENG. Vestibular weakness or canal paresis was considered when the sum of the slow-phase velocity of nystagmus on one side was lower than 5°/s or both sides lower than 12°/s.

After the physical examination, all participants completed a questionnaire that included demographic and headache data. They were encouraged to describe the presence of vestibular symptoms considering the criteria of vestibular migraine from the ICHD-3 and Bárány Society.[31] Patients were additionally classified with vestibular migraine if they presented at least five episodes of vestibular symptoms lasting 5 min and 72 h that are associated with migraine features (migraine headache, visual aura, or photo- and phonophobia).[31] Furthermore, patients were asked about the occurrence of fall events during the past 12 months. Fall events were defined according to the World Health Organization as "inadvertently coming to rest on the ground, floor or other lower level, excluding intentional change in position to rest in furniture, wall or other objects."[32] In addition, the following questionnaires were administered: Falls Efficacy Scale – International (FES-I),[33] Dizziness Handicap Inventory (DHI),[34] Tampa Scale for Kinesiophobia (Tampa),[35] and the Patient Health Questionnaire (PHQ-9).[36] All included questionnaires presented adequate validity and reliability.[35-39]

Data analysis

The sample size was calculated through a 2-tailed independent *t* test based on data from a pilot study including 10 patients and 10 controls. A mean difference of 10% between groups in the SOT composite score, which encompasses the perception thresholds of the vestibular, visual, and somatosensory inputs, resulted in a Cohen's *d* effect size of 0.88. The power and the alpha level were set at 90% and 5%, respectively, resulting in a minimum of 28 participants in each group. For Pearson's correlation analysis, a number of 84 subjects was considered adequate to detect a weak correlation of 0.3, with 80% of power and 5% of alpha level.[40]

This was the primary analysis of the data set, and all methods were chosen a priori based on the study hypothesis. Descriptive statistics was presented through means, standard deviations, and frequencies (%). Demographic data, questionnaires, and otoneurological outcomes were compared among groups using 2-tailed hypothesis test based on one-way analysis of variance or Kruskal–Wallis test according to the normal distribution of data verified with the Kolmogorov–Smirnov test ($p > 0.05$). We used Bonferroni or Dunn's as post-hoc tests. For categorical data, we used the Chi-square or Fisher tests.

We ran three multivariate analyses of variance to contrast the four groups for the six SOT conditions considering the variables sway area, sway speed, and the standard scores provided by the equipment (composite score and scores from the visual, vestibular, and somatosensory systems). We used Bonferroni adjustment for pairwise comparisons to prevent type 1 errors. Because heterogeneous distribution of vestibular migraine diagnosis was observed among groups, the analysis of variance was repeated using this factor as a covariate (multivariate analysis of covariance).

Furthermore, we carried out Pearson's correlation between the composite SOT and the FES-I, DHI, Tampa, PHQ-9 questionnaires, and migraine and aura frequency. Positive or negative correlations less than 0.3 were considered weak, moderate ranging from 0.31 to 0.70, and strong when greater than 0.70. All statistical analyses were carried out using SPSS (version 26), with a significance level set at $p < 0.05$. There were no missing data, and all the datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

RESULTS

Table 1 presents the sample characteristics. Thirty percent ($n = 9$) of patients with chronic migraine had aura. Patients with migraine, especially CM and MWA, reported a high prevalence of falls and body instability. The prevalence of vestibular symptoms was also high in patients with migraine, and patients with aura had the highest prevalence of symptoms during the ictal phase. The groups also differed among the self-report of vestibular symptom types. Dizziness was more prevalent, followed by postural symptoms, and external and internal vertigo, especially in the chronic and aura groups. The prevalence of patients who fulfilled vestibular migraine criteria also differed among the groups: MWA (73%, $n = 22$), MWoA (27%, $n = 8$), and CM (60%, $n = 18$). Patients with aura and CM had a greater concern of falls according to the FES-I scale. Also, in contrast to controls, all migraine groups presented higher scores for dizziness disability (DHI), kinesiophobia (Tampa), and depression (PHQ-9). Patients with chronic migraine also presented higher PHQ-9 scores compared to the MWoA group.

The results of the SOT demonstrated lower composite scores among all migraine groups than controls (Table 2). The MWA and CM groups also had lower composite scores than patients with MWoA. Lower scores in the visual and vestibular symptoms were found in the groups with CM and MWA compared to the MWoA and control groups. Scores for the somatosensory system were lower in the MWA group compared to MWoA and controls (Table 2). The vestibular migraine diagnosis as a covariate did not significantly influence the results of the composite score ($F = 3.33$, $p = 0.070$), visual score ($F = 2.11$, $p = 0.149$), vestibular score ($F = 1.88$, $p = 0.172$), and somatosensory score ($F = 0.00$, $p = 0.993$).

The SOT composite score presented a significant negative correlation ranging from weak to moderate with the following headache and psychosocial features: FES-I ($r = -0.44$, 95% confidence interval [CI] = −0.57 to −0.30), DHI ($r = -0.37$, 95% CI = −0.54 to −0.19), Tampa ($r = -0.38$, 95% CI = −0.45 to −0.06), PHQ-9 ($r = -0.25$, 95% CI = −0.53 to −0.22), migraine frequency ($r = -0.38$, 95% CI = −0.54 to −0.22), aura frequency ($r = -0.26$, 95% CI = −0.38 to −0.13), and age ($r = -0.21$, 95% CI = −0.37 to −0.05).

Figure 2 demonstrates the sway area of the CoP in each of the SOT conditions. Patients with aura had a greater sway area than controls and patients with MWoA for all six conditions. In conditions 3 and 4, the MWA group also exhibited differences compared to the CM group. In conditions 4, 5, and 6, patients with CM had greater sway area than controls. The vestibular migraine diagnosis as a covariate did not significantly influence the results of the sway area in all conditions (*F* ranged from 0.00 to 0.71, *p* values ranged from 0.791 to 0.987).

Sway-speed differences were also observed among groups (Figure 3). The MWA group had greater sway speed compared to

TABLE 1 Sample demographic characteristics exhibited through mean (SD) and percentages (%, *n*)

	Control group $n = 30$	Migraine without aura $n = 30$	Migraine with aura $n = 30$	Chronic migraine $n = 30$	*Sig.*
Age (years)	31.3 (9.3)	32.5 (8.7)	32.2 (8.3)	34.6 (10.0)	$F = 0.68$, $p = 0.556$
BMI (kg/cm^2)	24.9 (4.1)	24.1 (3.6)	24.5 (4.2)	23.8 (2.9)	$F = 0.51$, $p = 0.670$
Migraine onset (y)	–	15.5 (7.8)	18.0 (9.2)	18.0 (10.9)	$F = 0.73$, $p = 0.485$
Migraine frequency (attacks/mo)	–	7.3 (3.3)‡	7.6 (2.9)‡	23.3 (5.8)	**$F = 141.17$, $p < 0.0001$**
Migraine duration (h)	–	17.8 (20.5)	34.0 (29.4)	26.2 (27.5)	$F = 2.87$, $p = 0.062$
Migraine intensity (NRS: 0–10)	–	7.4 (1.3)	7.6 (1.9)	8.1 (1.7)	$F = 1.15$, $p = 0.319$
Aura frequency (attacks/mo)	–	0 (0)	4.1 (2.5)†	1.9 (4.1)†	**$F = 16.46$, $p < 0.0001$**
Self-report of falls (%, *n*)	3%, 1	30%, 9	73%, 22	60%, 18	**$x^2 = 36.343$, $p < 0.0001$**
Number of falls (last 12 mo)	0.3 (0.5)	1.4 (2.4)	4.6 (5.8)*	4.4 (7.2)*	**$F = 5.92$, $p = 0.001$**
Self-report of body instability (%)	33%, 10	67%, 29	80%, 24	70%, 21	**$x^2 = 15.75$, $p < 0.001$**
Falls/body instability onset (y)	3.0 (6.4)	7.7 (8.1)	7.8 (7.6)	9.2 (10.7)*	**$F = 3.16$, $p = 0.030$**
Ictal vestibular symptoms (%, *n*)	0%, 0	60%, 18	87%, 26	77%, 23	**$x^2 = 54.98$, $p < 0.001$**
Classification of vestibular symptoms					
Internal vertigo	0%, 0	17%, 5	13%, 4	40%, 12	**$x^2 = 17.26$, $p < 0.001$**
External vertigo	3%, 1	20%, 6	30%, 9	27%, 8	**$x^2 = 7.92$, $p = 0.042$**
Dizziness	7%, 2	43%, 13	63%, 19	67%, 20	**$x^2 = 27.61$, $p < 0.0001$**
Postural symptoms	13%, 4	37%, 11	70%, 21	47%, 14	**$x^2 = 20.43$, $p < 0.0001$**
Interictal vestibular symptoms (%, *n*)	13%, 4	37%, 11	57%, 17	50%, 15	**$x^2 = 13.81$, $p = 0.003$**
Fulfill the vestibular migraine criteria (%, n)	0%, 0	27%, 8	73%, 22	60%, 18	**$x^2 = 41.30$, $p < 0.0001$**
Prophylactic medication (%, *n*)					
Beta-blockers	0%, 0	7%, 2	13%, 4	7%, 2	$x^2 = 3.20$, $p = 0.360$
Tricyclic antidepressants	3%, 1	10%, 3	17%, 5	30%, 10	**$x^2 = 12.80$, $p = 0.005$**
Serotonin norepinephrine reuptake inhibitors	7%, 2	10%, 3	10%, 3	27%, 8	$x^2 = 6.34$, $p = 0.096$
Antiseizure medications	0%, 0	13%, 4	13%, 4	17%, 5	$x^2 = 7.50$, $p = 0.058$
Questionnaires					
Falls Efficacy Scale–International (FES-I)	20.1 (4.5)	23.7 (5.5)	27.5 (4.9)*	27.3 (7.8)*	**$F = 10.82$, $p < 0.0001$**
Dizziness Handicap Inventory (DHI)	1.4 (4.9)	22.1 (23.0)*	39.7 (22.3)*†	31.9 (24.5)*	**$F = 19.97$, $p < 0.0001$**
Tampa Scale for Kinesiophobia	27.5 (6.4)	33.2 (8.0)*	38.8 (7.6)*†	37.6 (8.7)*	**$F = 13.04$, $p < 0.0001$**
Patient Health Questionnaire (PHQ-9)	2.4 (3.0)	6.1 (5.5)*	8.6 (6.0)*	9.7 (5.3)*†	**$F = 12.10$, $p < 0.0001$**

Notes: Bonferroni post-hoc *$p < 0.05$ versus control group, $^†p < 0.05$ versus migraine without aura group, $^‡p < 0.0001$ versus chronic migraine group. Significant results are indicated in bold.

Abbreviations: BMI, body mass index; NRS, numeric rating scale (0–10); SD, standard deviation.

controls in conditions 1 to 6, compared to MWoA in conditions 1 to 5, and compared to CM in conditions 2 and 3. Patients with CM had a faster sway speed in contrast to controls in condition 6. The vestibular migraine diagnosis as a covariate did not significantly influence the results of the sway speed in any conditions (F ranged from 0.05 to 0.87, p values ranged from 0.364 to 0.817).

There was a higher occurrence of falls during the SOT test among patients with migraine than controls, considering within-group prevalence and the number of trials. The calibration of the ENG test was normal for all participants. The four groups did not differ regarding abnormalities in the caloric testing, rotatory chair testing, and the presence of nystagmus or asymmetrical gain during the optokinetic test (Table 2).

DISCUSSION

For the first time to our knowledge, we showed that patients with migraine had lower composite SOT scores compared to controls. The

TABLE 2 Results of SOT test, occurrence of falls during the SOT, and vestibular testing outcomes

	Control group $n = 30$	Migraine without aura $n = 30$	Migraine with aura $n = 30$	Chronic migraine $n = 30$	*Sig.*
Composite score (mean, 95% CI)	82.4 (79.5 to 85.3)	76.5 (73.6 to 79.3)*	66.5 (63.6 to 69.3)*†	69.1 (66.3 to 72.0)*†	**$F = 24.95$, $p < 0.0001$**
Visual score (mean, 95% CI)	89.6 (84.2 to 94.9)	83.2 (77.9 to 88.6)	68.6 (63.3 to 74.0)*†	71.9 (66.5 to 77.2)*†	**$F = 13.17$, $p < 0.0001$**
Vestibular score (mean, 95% CI)	75.9 (71.3 to 80.4)	67.3 (62.7 to 71.8)	55.7 (51.2 to 60.3)*†	58.4 (53.8 to 63.0)*†	**$F = 15.77$, $p < 0.0001$**
Somatosensorial score (mean, 95% CI)	97.9 (96.3 to 99.6)	96.7 (95.0 to 98.3)	93.4 (91.8 to 95.1)*†	95.7 (94.1 to 97.3)	**$F = 5.36$, $p = 0.002$**
Prevalence of falls during SOT (%, *n*)	0%, 0	30%, 9	40%, 12	37%, 11	**$x^2 = 15.34$, $p = 0.002$**
Number of falls (median, IQR)†	0.0 (0.0, 0.0)	1.0 (1.0, 1.0)*	2.0 (1.8, 4.3)*	1.0 (1.0, 2.0)*	**$H = 15.98$, $p = 0.001$**
Vestibular functioning assessment (%, *n*)					
Spontaneous nystagmus with eyes open	3%, 1	3%, 1	0%, 1	3%, 1	$x^2 = 1.02$, $p = 0.795$
Spontaneous nystagmus with closed eyes	13%, 4	13%, 4	27%, 8	17%, 5	$x^2 = 2.48$, $p = 0.479$
Gaze nystagmus	3%, 1	13%, 4	7%, 2	7%, 2	$x^2 = 2.28$, $p = 0.516$
Optokinetic test, asymmetrical gain	27%, 8	20%, 6	23%, 7	10%, 3	$x^2 = 2.91$, $p = 0.405$
Rotatory chair test, asymmetrical response	10%, 3	0%, 0	3%, 1	7%, 2	$x^2 = 3.50$, $p = 0.320$
Vestibular weakness during caloric test	7%, 2	17%, 5	7%, 2	20%, 6	$x^2 = 3.88$, $p = 0.274$

Significant results are indicated in bold.

Abbreviations: CI, confidence interval; IQR, interquartile range; SOT, sensory organization test.

†Kruskal Wallis with Dunn's post-hoc. *$p < 0.05$ versus control group. †$p < 0.05$ versus migraine without aura.

composite SOT scores were moderately correlated with fear of falling, dizziness disability, kinesiophobia, and migraine frequency. Also, compared to patients without aura, patients with aura and chronic migraine had lower visual and vestibular SOT scores despite showing no differences in the otoneurological tests. Differences in sway area and speed between patients with aura and those with chronic migraine were recorded in the SOT conditions 4 to 6, in which somatosensory input is eliminated and the postural control relies mainly on the vestibular/visual systems.[16] These results were maintained even after adding the vestibular migraine diagnosis as a covariate. Furthermore, the occurrence of falls during the SOT test was greater in patients with migraine, especially in patients with aura and chronic migraine.

These results expand the knowledge in this field because they consider aspects that, to our knowledge, have not been assessed in previous studies, such as the vestibular system function,[1,2,5,6,8,14,15] presence of aura,[1,2,3,7,8,12,14,15] vestibular migraine diagnosis,[1,2,5,6,13,41] prophylactic medication intake,[1,2,6,7,8,15,41] and the presence of psychosocial factors.[1,2,3,5,6,7,8,14,15,41] The current results are in line with previous research reporting greater postural alterations in patients with aura[5,6,13] and CM,[5,13] or suggesting impairment of the vestibular system assessed with different posturography assessment protocols.[1,2,3,7,15] Furthermore, impairment of the visual system during balance evaluation with visual stimuli was also suggested by Lim et al.,[8] who indicated that patients with migraine showed impaired ability in the central integration of visual motion, as previously hypothesized.[42]

Regarding the contribution of each sensory system to postural balance, the current data highlighted that the vestibular system exhibited lower SOT scores in all groups, followed by the visual and somatosensory systems. Considering the SOT normative data,[43] all patients with migraine had lower composite somatosensory, visual, and vestibular scores than expected in individuals between 30 to 39 years old. As hypothesized, greater differences among groups were demonstrated for the visual and vestibular systems, except for the MWoA group, who did not differ from controls. They had better scores than patients with aura or CM. Interestingly, patients with MWA also presented a significant impairment of the somatosensory system, indicating an additional impairment in this subgroup.

We opted to expand the SOT analysis to provide more in-depth information regarding the postural behavior of patients with migraine and to allow a comparison to studies that used standardized balance outcomes such as sway area and speed. Excellent reliability has been verified for both sway area and speed,[44] and the latter has a high sensitivity to discriminate age and disease groups.[45] This detailed assessment of each SOT condition revealed further differences

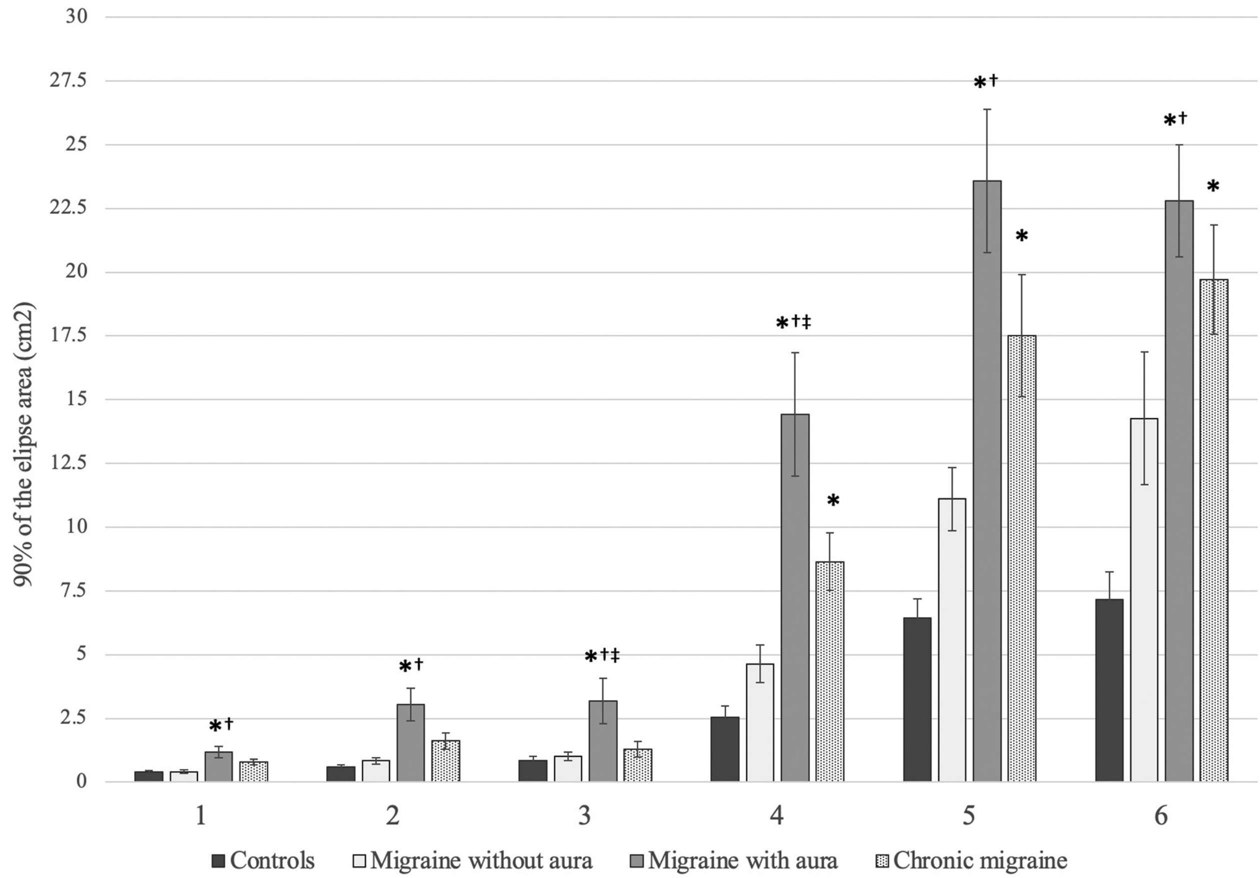

FIGURE 2 The mean and standard error of the sway area (cm^2) in each of the six conditions of the Sensory Organization Test in controls, patients with chronic migraine, migraine with and without aura. Condition 1: $F = 7.9$, $p < 0.0001$; condition 2: $F = 9.14$, $p < 0.0001$; condition 3: $F = 5.05$, $p = 0.002$; condition 4: $F = 13.9$, $p < 0.0001$; condition 5: $F = 14.2$, $p < 0.0001$; condition 6: $F = 10.8$, $p < 0.0001$. Bonferroni post-hoc $^*p < 0.01$ versus controls, $^†p < 0.05$ versus migraine without aura, $^‡p < 0.05$ versus chronic migraine

between MWA and CM groups, especially in conditions 2, 3, and 4, in which patients could not rely on visual and somatosensory cues.[28] Using this detailed approach, we observed balance--behavior differences between the groups with aura and CM. Patients with aura had a worse integration of all sensory systems related to posture maintenance, but in contrast to patients with CM, greater impairment of the vestibular system was found, followed by that of the somatosensory and visual systems.

The group differences regarding the vestibular system contribution were not detected in the standard otoneurological evaluation. This finding contrasts with the more frequent report of vestibular symptoms among patients with migraine, confirming the weak association between these two factors.[9,11,12] For this reason, it has been suggested that the otoneurological examination would not provide enough information in the assessment of patients with migraine.[11] Most of the patients with aura (80%) and CM (60%) fulfilled the vestibular migraine criteria proposed by the Bárány Society[31] and integrated in the Appendix of the ICHD-3.[46] Despite these data, the diagnosis of vestibular migraine was not a significant covariate for any outcome of the SOT test. This points toward a potential bias in studies assessing patients with vestibular migraine without differentiating among MWA, MWoA, and CM. Further studies controlling for these factors and a subsequent review of the vestibular migraine classification are needed, because recent reports have also demonstrated no influence of vestibular symptoms on the balance impairment of patients with migraine.[5,13]

Another relevant finding of this study is the clinical consequences of the sensory organization alterations in this population. Between 30% and 40% of patients with migraine have fallen during the SOT examination, with a mean of 1.1 times in the MWoA group, 2.2 times in the CM group, and 2.8 times in the MWA group. Patients reported a greater history of falls and reduced body stability, with higher rates of falls within the prior year, among patients with aura and CM, which is in accordance with a previous report.[4]

Our study also demonstrated for the first time an association between the SOT score and fear of falls, dizziness disability, and kinesiophobia. The greater the scores in these questionnaires, the worse the overall performance in the SOT. The SOT composite also had a negative and moderate correlation with migraine frequency, and despite being significant, its correlation with depression scores and aura frequency was weak. Previous reports verified a correlation between SOT outcomes and performance of daily life activities[24] or the rate of falls.[17,24]

Our study had some limitations. First, data were collected in a tertiary headache center, and therefore, patients with greater

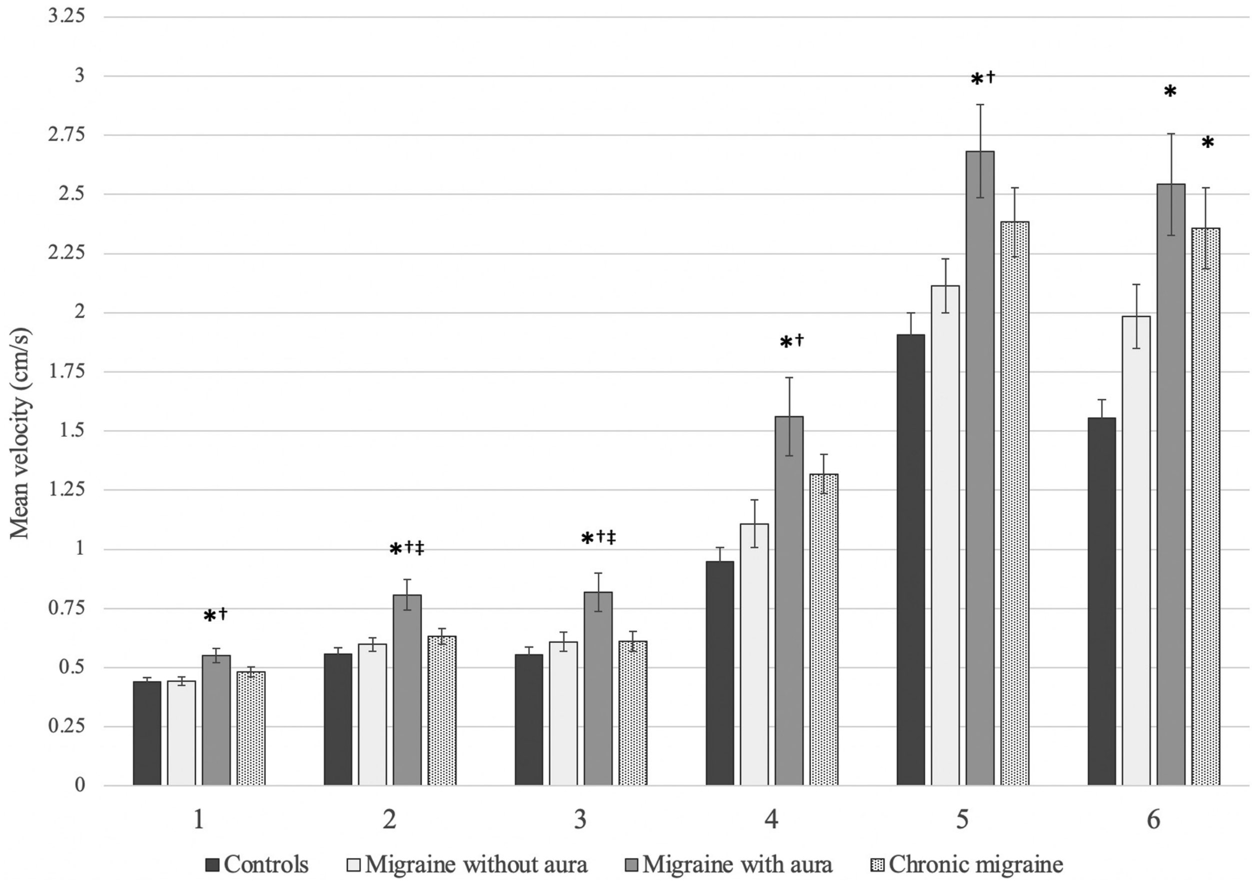

FIGURE 3 The mean and standard error of sway speed (cm/s) in each of the six conditions of the Sensory Organization Test in controls, patients with chronic migraine, migraine with and without aura. Condition 1: $F = 5.27$, $p = 0.002$; condition 2: $F = 7.05$, $p < 0.0001$; condition 3: $F = 4.85$, $p = 0.003$; condition 4: $F = 5.86$, $p = 0.001$; condition 5: $F = 5.53$, $p = 0.001$; condition 6: $F = 7.62$, $p < 0.0001$. Bonferroni post-hoc: $^{*}p < 0.01$ versus controls, $^{\dagger}p < 0.05$ versus migraine without aura, $^{\ddagger}p < 0.05$ versus chronic migraine

severity were included. This fact should be considered in the generalization of the results, as should the absence of males in our sample. Our study also cannot suggest the mechanisms responsible for the balance abnormalities among patients with migraine, because the SOT protocol assesses the functional sensory integration of balance. Despite these limitations, this was the first study that provided evidence for sensory systems' impairment in migraine, and it has direct clinical implications for its management. Our results highlight the need to consider these factors for clinical practice and future studies to improve migraine care. Effective intervention programs should be tailored according to migraine subtype, aiming for the rehabilitation of the functioning of the vestibular and visual systems. In patients with aura, the somatosensory system should also be considered.

CONCLUSION

Patients with migraine exhibited balance impairment, which was correlated with psychosocial outcomes. Patients with aura demonstrated functional dysfunction in all three sensory systems. In contrast, patients with CM had lower vestibular and visual scores, despite no differences between groups in the otoneurological assessment. More frequent fall events were observed among patients with migraine. The presence of aura and CM, and not the vestibular migraine diagnosis, is related to reduced balance performance. These results point toward a need for a more tailored rehabilitation to restore the sensory systems responsible for postural control in patients with migraine, especially when aura or a high frequency of attacks are reported.

ACKNOWLEDGMENTS

The authors thank the Lapomh research group and the FAPESP Foundation, which supported this project through the grants 2015/18031-5 and 2017/07482-1. Open Access funding enabled and organized by Projekt DEAL.

CONFLICTS OF INTEREST

All authors agree with the content of this manuscript. None of the authors have any conflict of interest with any content of this manuscript.

AUTHOR CONTRIBUTIONS

Study concept and design: Gabriela F. Carvalho, Marcelo E. Bigal, Debora Bevilaqua-Grossi, Fabiola Dach. *Acquisition of data*: Gabriela F. Carvalho, Carina F. Pinheiro. *Analysis and interpretation of data*:

Gabriela F. Carvalho, Kerstin Luedtke, Renato Moraes, Carina F. Pinheiro, Tenysson W. Lemos. *Drafting of the manuscript*: Gabriela F. Carvalho. *Revising it for intellectual content*: Gabriela F. Carvalho, Kerstin Luedtke, Renato Moraes, Marcelo E. Bigal, Fabiola Dach, Debora Bevilaqua-Grossi. *Final approval of the completed manuscript*: Gabriela F. Carvalho, Kerstin Luedtke, Carina F. Pinheiro, Renato Moraes, Camila G. Carneiro, Marcelo E. Bigal, Fabiola Dach, Tenysson W. Lemos, Debora Bevilaqua-Grossi.

ORCID

Gabriela F. Carvalho https://orcid.org/0000-0002-4442-2040
Carina F. Pinheiro https://orcid.org/0000-0002-2745-2272

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How to cite this article: Carvalho GF, Luedtke K, Pinheiro CF, et al. Migraine and balance impairment: Influence of subdiagnosis, otoneurological function, falls, and psychosocial factors. *Headache*. 2022;62:548–557. doi:10.1111/head.14309