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ORIGINAL RESEARCH

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# Hearing, balance, and imaging assessment in adolescent Menière's disease: A retrospective analysis

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## Abstract

**Objective:** To retrospectively analyze clinical features in adolescent Menière's disease (MD).

**Methods:** The medical records of adolescents with MD (11–17 years old) from May 2014 to March 2023 in Shandong Provincial ENT Hospital were retrospectively analyzed, including clinical features, a battery of auditory and vestibular function tests, sensory organization test, and imaging assessments. Patients with recurrent vertigo of childhood (RVC) were as controls.

**Results:** Compared with RVC, adolescent MD showed higher pure tone average threshold ($p < .001$), lower speech discrimination score ($p = .014$), and lower otoacoustic emission pass rates ($p = .005$). Adolescents with MD exhibited significant reduction in equilibrium score (Conditions 1, 5, and 6; $p1 = .035$; $p5 = .033$; $p6 = .003$), composite sensory score ($p = .014$), and vestibular sensory score ($p = .029$). Adolescents with bilateral MD exhibited worse performance in equilibrium score and strategy score compared to adolescents with unilateral MD. For the affected ear, the more severe endolymphatic hydrops detected by gadolinium-enhanced magnetic resonance imaging, the higher the auditory brainstem response threshold ($r = .850$, $p = .007$), and the lower the otoacoustic emission pass rate ($r = -.976$, $p < .001$).

**Conclusion:** Adolescent MD has similar vestibular information inputs with that of RVC, but the ability for the nerve center to use these clues to maintain balance is worse in adolescents with MD. There were potential differences in vestibular weights

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in adolescents with unilateral and bilateral MD, also potential effects on vision and proprioception.

**Level of Evidence:** Level 4.

KEYWORDS
adolescents, hearing loss, Menière's disease, sensory organization test, vestibular function

## 1 | INTRODUCTION

Menière's disease (MD) mostly affected middle-aged patients with a mean age of 40–50 years. MD in children is rare, accounting for 1%–2.3% incidence in patients with MD,[1–3] and 1.5%–2.9% in children with vertigo or dizziness.[1,4] Most of the published literatures on MD in children are case series. A recent study retrospectively analyzed the clinical features and audiovestibular function of 24 children with MD.[5]

Diagnosis is straightforward in typical presentations of MD, yet a proportion of patients present with atypical balance symptoms, resulting in diagnostic difficulties separating MD from other recurrent vertigo conditions. Audiovestibular function tests and imaging help MD diagnosis and comprehensive assessment. Besides a battery of audiovestibular function tests, postural control and balance maintaining were assessed by sensory integration test (SOT), which is widely used in our clinical center.[6] Imaging evaluation includes magnetic resonance imaging (MRI) and high-resolution computerized tomography (CT). CT helps rules out inner ear malformations. MRI contributes to rule out central lesions, and observe endolymphatic hydrops (EH) with intravenous enhancers.[7] In addition, electrocochleogram is another way to evaluate EH.

In the current retrospective study, we reviewed the medical records of 20 adolescents with MD who completed most of their examinations. The comparison was performed with another common vertigo disease in children, recurrent vertigo of children. Correlation analysis of clinical features and a battery of examinations were performed to reveal the underlying connection of adolescent MD.

## 2 | MATERIALS AND METHODS

### 2.1 | Participants

The medical documents of 20 adolescents (11–17 years old) who visited our vertigo clinic in a tertiary ENT medical center, from May 2014 to March 2023, with complaints of vertigo/dizziness were retrospectively analyzed. At present, there are no diagnostic criteria specifically for adolescent MD (Table S1). Adolescents were diagnosed with MD based on the American Academy of Otolaryngology—Head and Neck Surgery (AAO-HNS) 2015 criteria.[8] Through a retrospective review of cases, we selected adolescents who were matched for age and gender and diagnosed with recurrent vertigo of childhood (RVC) according to the diagnostic criteria consensus document of the Classification Committee of Vestibular Disorders of the Barany Society and the International Headache Society in 2021.[9] There was no significant difference in baseline between the patients in the two disease groups (age: 14.4 ± 1.8, male/female: 9/11 in MD and age: 13.6 ± 1.5, male/female: 9/11 in RVC) (Figure 1) (Table 1).

### 2.2 | Procedures and measures

#### 2.2.1 | Clinical data collection

By retrospectively reviewing patient records, the following medical history indicators were collected: sex, age, affected ear, age of onset, disease duration, duration and frequency of vertigo attack, duration between last attack and admission, rotational or nonrotational dizziness, the cochlear symptoms associated with vertigo attack, history of migraines, motion sickness and allergies, family history of dizziness and headache, and disease staging.

Adolescents with MD and RVC underwent pure tone audiometry (PTA), speech discrimination score (SDS), auditory brainstem response (ABR), otoacoustic emission (OAE), and tympanograms to evaluate their hearing levels. Additionally, they received a battery of vestibular function tests, including video head impulse (vHIT), caloric test, ocular vestibular-evoked myogenic potentials (oVEMP) and cervical vestibular-evoked myogenic potentials (cVEMP). Regarding VEMPs, absent responses or an amplitude ratio greater than 30% in the weaker response ear were considered abnormal.[10] The SOT was used to assess postural control and balance ability. Imaging evaluation was performed to assess the inner ear and cranial lesions in adolescents with MD, including temporal bone high-resolution computed tomography (HRCT) and cranial MRI. In addition, delayed gadolinium (Gd)-enhanced MRI (Gd-MRI) of the inner ear and electrocochleography were used to analyze EH in MD. According to ratio of the area of the endolymphatic space to that of the fluid space (sum of the endolymphatic and perilymphatic spaces) in the vestibule measured on tracings of image, we categorized the degree of EH into none, mild, and significant.[11] It should be noted that not all adolescents underwent all of these examinations, the number of participants for each evaluation was specified in the respective tables. Based on the diagnostic criteria for MD established by AAO-HNS in 2015,[8] all adolescents with MD reported experiencing rotational vertigo lasting between 20 min to 12 h. Based on the recent vertigo attacks prior to hospital admission, this study categorized the symptoms of vertigo into three groups: less than 20 min, 20 min to 12 h, and more than 12 h. We represent the

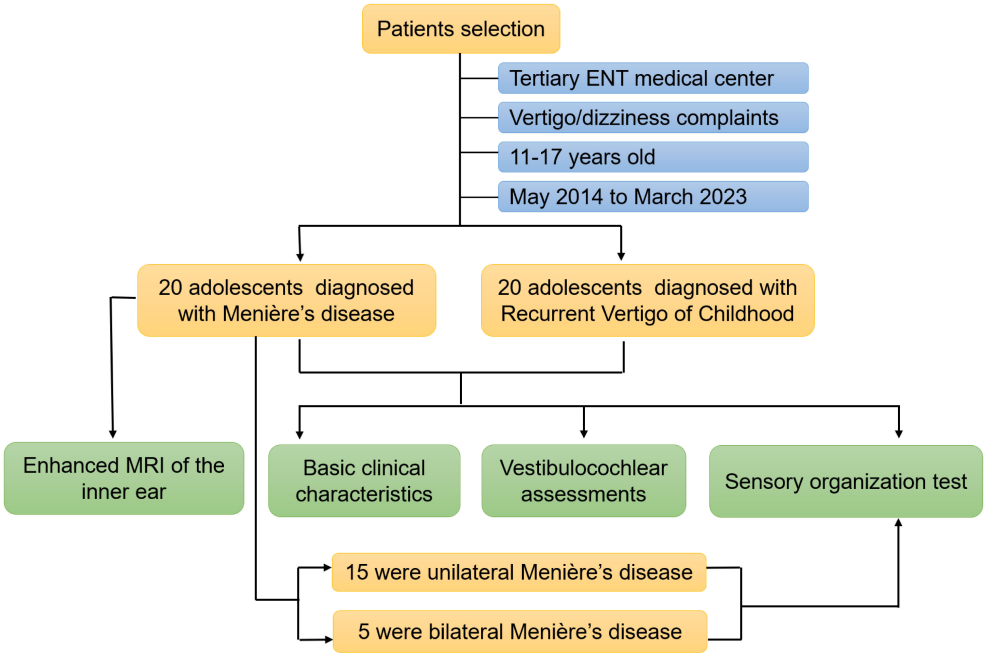


**FIGURE 1** The composite score and duration of vertigo attack.

results of PTA by averaging the hearing thresholds at 0.5, 1.0, and 2.0 kHz[12] (Table S1). For caloric test, the value of unilateral warmth (UW) less than 20% was considered to be normal in our laboratory.[13]

#### 2.2.2 | Data analysis

Data analyses were analyzed with SPSS 27.0 statistical software. Continuous variables were expressed as mean ± standard deviation (SD) and compared with independent sample *t*-tests. The Mann–Whitney test was used as an alternative to a *t*-test when the data were not normally distributed and expressed as median (interquartile range). Categorical variables were expressed as frequencies and percentages and analyzed with chi-square tests and Fisher's exact test where appropriate. Correlation analysis was conducted by Spearman's test. Two-tailed *p*-value <.05 was considered as the statistically significant.

#### 2.2.3 | Ethics statement

The studies involving human participants were reviewed and approved by Shandong Provincial ENT Hospital Ethical Committee. Oral informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

## 3 | RESULTS

### 3.1 | Basic clinical characteristics of adolescents with MD

By comparing the clinical features of MD and RVC, we observed a higher prevalence of rotational vertigo (100.0% vs. 45.0%, $p < .001$) and migraine headache (30.0% vs. 0.0%, $p = .027$) in adolescents with MD. Nineteen (95%) adolescents with MD exhibited cochlear symptoms such as tinnitus, aural fullness, and hearing loss associated with vertigo attack, whereas only two (10%) individuals in the RVC group presented these symptoms ($p < .001$). Additionally, the percentage of adolescents with a history of motion sickness in RVC (61.1%) is greater than in MD (11.1%, $p = .002$) (Table 1).

Among the 20 MD adolescents, 10 cases (50.0%) were affected in the left ear, 5 cases were affected in the right ear, and 5 cases were affected in both ears. In addition, the hearing stage classification based on PTA showed that there were six cases in Stage I, five cases in Stage II, seven cases in Stage III, and two case in Stage I (Table 1).

### 3.2 | Comparison of vestibulocochlear assessments between MD and RVC

Adolescents with MD had significantly lower hearing level compared to RVC. The average hearing threshold in PTA of the affected ear in adolescents with MD was 43.9 ± 28.7 dB hearing level (HL), which was significantly higher than that of RVC (5.7 ± 2.4 dB HL, $p < .001$). Additionally, the SDS in the affected ear of adolescents with MD was 69.4 ± 32.4%, significantly lower than that of RVC (95.3 ± 3.0%, $p = .014$). Moreover, the OAE failure rate in adolescents with MD was 66.7%, which is significantly higher than that of RVC (0%; $p = .005$). However, there were no significant differences observed in the vestibular function assessment between the two groups (all *p*-values >.05) (Table 2).

### 3.3 | Comparison of SOTt between MD and RVC

The SOT results indicated that the equilibrium score of adolescents with MD were significantly lower than those of RVC in Condition

**TABLE 1** Comparison of clinic features between MD and RVC.

| Clinic features | MD, $n = 20$ | RVC, $n = 20$ | $p$-values |
|---|---|---|---|
| Sex | | | 1.000 |
| Female | 11 (55.0%) | 11 (55.0%) | |
| Male | 9 (45.0%) | 9 (45.0%) | |
| Age (year) | 14.4 ± 1.8 | 13.6 ± 1.5 | .119[a] |
| Body mass index (kg/m$^2$) | 23.7 ± 4.2<br>$n = 13$ | 20.9 ± 4.1<br>$n = 20$ | .071 |
| Age of onset (year) | 13.1 ± 2.7 | 12.5 ± 2.2 | .484[a] |
| Duration (month) | 12.0 (3.3,25.5) | 3.0 (0.7,21.0) | .162[a] |
| Vertigo attack | | | .311 |
| ≥Twice a month | 12 (60.0%) | 15 (75.0%) | |
| <Twice a month | 8 (40.0%) | 5 (25.0%) | |
| Duration of vertigo attack | | | .753 |
| <20 min | 2 (10.0%) | 3 (15.0%) | |
| 20 min to 12 h | 14 (70.0%) | 11 (55.0%) | |
| >12 h | 4 (20.0%) | 6 (30.0%) | |
| Duration between last attack and admission (day) | 1.0 (1.0,7.0) | 3.0 (1.0,11.5) | .347[a] |
| **Tinnitus and ear fullness associated with vertigo attack** | **19 (95%)** | **2 (10%)** | **<.001** |
| **Vertigo** | | | **<.001** |
| Rotational | 20 (100.0%) | 9 (45.0%) | |
| Nonrotational | 0 (0.0%) | 11 (55.0%) | |
| **Migraine headache** | **6 (30.0%)** | **0 (0.0%)** | **.027** |
| **Motion sickness** | **2 (10.0%)** | **11 (55.0%)** | **.002** |
| Allergy | 2 (10.0%) | 5 (25.0%) | .405 |
| Family history | 2 (10.0%) | 7 (35.0%) | .130 |
| Affected ear | | | |
| Bilateral | 5 (25.0%) | – | |
| Right | 5 (25.0%) | – | |
| Left | 10 (50.0%) | – | |

*Note*: Bold indicates $p<0.05$.
Abbreviations: MD, Meniere's disease; RVC, recurrent vertigo of childhood.
[a]Data are shown as mean (SD), when the data did not present a normal distribution, the $t$-test was replaced by Mann–Whitney rank sum test to compare two groups.

1 ($p = .035$), Condition 5 ($p = .033$), and Condition 6 ($p = .003$). Moreover, the sensory ratio analysis revealed significantly lower scores in composite ($p = .014$) and vestibular ($p = .029$) domains for adolescents with MD compared to adolescents with RVC. However, there was no significant difference between the two groups in strategy score (all $p$-values >.05) (Table 3).

## 3.4 | The lesion side on SOT

First, the Spearman correlation analysis revealed that adolescents with bilateral Meniere's disease consistently exhibited lower equilibrium score compared to those with unilateral MD in Condition 1 ($p = .040$), Condition 2 ($p = .043$), Condition 3 ($p = .043$), and Condition 4 ($p = .044$). However, only Student's $t$-test for Condition 2 demonstrated a significant difference ($p = .022$). Second, the Spearman correlation analysis indicated that adolescents with bilateral Meniere's disease had lower strategy score compared to those with unilateral MD in Condition 1 ($p = .028$), Condition 2 ($p = .005$), and Condition 4 ($p = .044$). Simultaneously, Student's $t$-test also confirms the aforementioned findings ($p1 = .037$; $p2 = .005$; $p4 = .039$) (Tables 4 and 5).

## 3.5 | Duration of vertigo attack and SOT

There was an inverse relationship between the duration of vertigo attack and the composite score in the sensory ratio analysis. As the duration of vertigo attack increased, the composite score tended to be lower ($r = -.62$, $p = .042$) (Figure S1 A, B).

## 3.6 | Imaging assessments of children with MD

Out of the 20 adolescents with MD, 12 underwent Gd-MRI. Among them, four (33.3%) showed no abnormality, three (25.0%) had mild EH, and five (47.7%) had significant EH. Furthermore, among the

**TABLE 2** Comparison of audiovestibular evaluation between MD and RVC.

| Evaluation | MD, $n = 20$ | RVC, $n = 20$ | Statistic | $p$-values |
|---|---|---|---|---|
| **Pure tone audiometry (dB HL)** | **43.9 ± 28.7** | **5.7 ± 2.4** | **5.940** | **<.001** |
| **Speech discrimination score (%)** | **69.4 ± 32.4 $n = 13$** | **95.3 ± 3.0 $n = 11$** | **−2.869** | **.014** |
| **Otoacoustic emission (fail)** | **8 (66.7%) $n = 12$** | **0 (0%) $n = 8$** | **8.889[a]** | **.005** |
| Tympanogram (normal) | 20 (100.0%) | 20 (100.0%) | — | — |
| SP/AP > 0.4 | 5 (50.0%) $n = 10$ | — | — | — |
| Video head impulse test | $n = 18$ | $n = 20$ | | |
| Anterior | 1.03 ± 0.09 | 0.96 ± 0.17 | 1.493 | .144 |
| Horizontal | 0.93 ± 0.16 | 0.98 ± 0.07 | −1.375 | .178 |
| Posterior | 0.98 ± 0.09 | 0.98 ± 0.06 | 0.277 | .784 |
| cVEMP (abnormal) | 6 (33.3%) $n = 18$ | 9 (45.0%) $n = 20$ | 0.540[a] | .522 |
| oVEMP (abnormal) | 6 (33.3%) $n = 18$ | 13 (65.0%) $n = 20$ | 3.800[a] | .103 |
| Caloric test (abnormal) | 7 (50.0%) $n = 14$ | 9 (47.4%) $n = 19$ | 0.022 | 1.000 |
| UW (%) | 22.6 ± 18.6 $n = 14$ | 28.3 ± 24.7 $n = 19$ | −0.720 | .477 |

*Note*: Data are shown as mean (SD). Not all the children completed all the auditory–vestibular evaluation. Bold indicates $p<0.05$.
Abbreviations: cVEMP, cervical vestibular evoked myogenic potential; MD, Meniere's disease; oVEMP, ocular vestibular evoked myogenic potential; RVC, recurrent vertigo of childhood; SP/AP, summating potential/action potential; UW, unilateral warmth.
[a]Chi-square value.

12 adolescents with MD who underwent temporal bone HRCT, 8 (66.7%) were found to have a high jugular bulb and/or anterior sigmoid sinus, while 4 (33.3%) showed no abnormalities. Moreover, among the seven adolescents with MD who underwent cranial MRI, only one (14.3%) was diagnosed with arachnoid cyst, while the remaining six (85.7%) showed no abnormality (Table 6).

### 3.7 | Correlation between Gd-MRI and audiovestibular evaluation

The degree of EH detected by Gd-MRI was significantly associated with hearing impairment in adolescents with MD. Specifically, for the affected ear, the more severe of EH, the higher the ABR threshold ($r = .850$, $p = .007$), and the lower the OAE pass rate ($r = -.976$, $p < .001$) (Table 7).

## 4 | DISCUSSION

### 4.1 | Comparison of clinical features in adolescents with MD and RVC

The adolescents with MD had a higher proportion of rotational vertigo compared with the adolescents with RVC. Rotational vertigo is a typical form of MD and as one of the diagnostic criteria, while vestibular symptoms in adolescents with RVC are more varied, including vertigo, dizziness, tilting, and rocking et al.[14] Due to the small number of cases, nonrotational vertigo has not been further subdivided and analyzed. Adolescents with MD had a higher incidence of migraine or headache symptoms while adolescents with RVC had a higher history of motion sickness. Although some of the children in our study presented with hearing loss accompanied by migraine symptoms, the frequency of their migraine attacks did not meet the diagnostic criteria for vestibular migraine, which requires at least 50% of vestibular symptoms to be accompanied by at least one migraine feature. Therefore, based on the current evidence and diagnostic criteria, they were diagnosed with Ménière's disease. The high comorbidity of migraine and MD in adults has been reported in many studies.[15] This study revealed similar epidemiological characteristics of MD in adolescents. These differences are consistent with the clinical impression and reflect the manifestations of the disease itself. The differential diagnosis of vestibular migraine and MD has been the focus of research since vestibular migraine can mimic MD. However, vestibular migraine can result in mild hearing loss but rarely moderate to severe deafness even experienced a long course of disease.

### 4.2 | Analysis of SOT in adolescents with MD

This has been the first study to investigate the sensory organization and posture control strategies in adolescents with MD. Previous

**TABLE 3** Comparison of sensory organization test between MD and RVC.

| Evaluation | MD, $n = 11$ | RVC, $n = 11$ | $t$ | $p$-values |
|---|---|---|---|---|
| Equilibrium score | | | | |
| **Condition 1** | **91.6 ± 3.1** | **94.2 ± 1.9** | **−2.264** | **.035** |
| Condition 2 | 88.3 ± 7.0 | 91.8 ± 3.6 | −1.400 | .185 |
| Condition 3 | 85.4 ± 13.3 | 91.2 ± 5.9 | −1.318 | .203 |
| Condition 4 | 66.2 ± 22.0 | 77.8 ± 13.3 | −1.470 | .158 |
| **Condition 5** | **59.4 ± 13.1** | **70.1 ± 8.3** | **−2.297** | **.033** |
| **Condition 6** | **54.9 ± 11.4** | **71.2 ± 6.9** | **−3.358** | **.003** |
| Strategy score | | | | |
| Condition 1 | 95.5 ± 1.2 | 95.9 ± 1.2 | −0.861 | .400 |
| Condition 2 | 94.2 ± 2.1 | 94.9 ± 1.7 | −0.854 | .404 |
| Condition 3 | 92.7 ± 6.6 | 94.7 ± 2.3 | −0.951 | .354 |
| Condition 4 | 82.6 ± 5.6 | 84.3 ± 7.1 | −0.614 | .546 |
| Condition 5 | 76.0 ± 12.4 | 76.0 ± 10.8 | −0.003 | .998 |
| Condition 6 | 78.5 ± 6.9 | 80.0 ± 6.6 | −0.508 | .617 |
| Sensory ratio analysis | | | | |
| **Composite** | **65.7 ± 15.6** | **95.8 ± 5** | **−2.679** | **.014** |
| Somatosensory | 96.8 ± 5.0 | 97.4 ± 3.6 | −0.831 | .416 |
| Visual | 71.9 ± 23.8 | 82.5 ± 14.2 | −1.261 | .222 |
| **Vestibular** | **54.0 ± 26.0** | **74.4 ± 8.7** | **−2.465** | **.029** |
| Visual preference | 91.9 ± 10.0 | 98.1 ± 9.6 | −1.479 | .155 |

*Note*: Data ar shown as mean (SD). Not all the children completed all the auditory–vestibular evaluation.
Bold indicates $p<0.05$.
Abbreviations: MD, Meniere's disease; RVC, recurrent vertigo of childhood.

**TABLE 4** Correlation between the lesion side and sensory organization test.

| Variables | Spearman correlation, $n = 11$ | $p$-values |
|---|---|---|
| Equilibrium score | | |
| **Condition 1** | **−.654** | **.040** |
| **Condition 2** | **−.648** | **.043** |
| **Condition 3** | **−.648** | **.043** |
| **Condition 4** | **−.646** | **.044** |
| Condition 5 | −.414 | .268 |
| Condition 6 | −.207 | .593 |
| Strategy score | | |
| **Condition 1** | **−.688** | **.028** |
| **Condition 2** | **−.800** | **.005** |
| Condition 3 | −.191 | .597 |
| **Condition 4** | **−.646** | **.044** |
| Condition 5 | .152 | .674 |
| Condition 6 | .229 | .525 |
| Sensory ratio analysis | | |
| Composite | −.551 | .079 |
| Somatosensory | −.584 | .059 |
| Visual | −.356 | .283 |
| Vestibular | −.452 | .163 |
| Visual preference | .227 | .502 |

*Note*: Bold indicates $p<0.05$.

studies have described the characteristics of peripheral vestibular function in adolescents with MD,[5] but due to the small number of cases or poor coordination in adolescents, no studies have assessed balance ability in adolescents with MD. In addition, previous studies have reported comparative characteristics of minor and adult patients with MD. Since vision, proprioception, and vestibular perception are on developmental stage in adolescents,[16] we used age- and sex-matched adolescents with RVC as a control group in this study.

Adolescents with MD have poorer balance than RVC that is evidenced by their lower composite ES scores in the SOT. When standing under less challenging conditions (Conditions 2–4), the ES score in the MD group to maintain balance did not differ from those of the control group even though the mean score with MD is a little lower than the controls. However, adolescents with MD had difficulty adjusting their center of gravity and swayed significantly more than their developing counterparts in Conditions 5 and 6 in which they needed to rely more on vestibular input for balance control, with a significantly lower scores under Conditions 5 and 6 and less vestibular sensory weights. These findings reflect the fact that adolescents with MD have worse balance control, particularly in environments where they must depend on vestibular signals. Notably, peripheral vestibular function indicators, including vHIT VOR gain value, unilateral weakness of caloric test, the abnormal rate of oVEMP and cVEMP, was not significantly different in the adolescents with MD compared with the control group, and the average scores in the two groups were very similar. These findings imply that adolescents with MD have similar

**TABLE 5** The effect of lesion side on sensory organization test.

| Variables | Unilateral, $n = 8$ | Bilateral, $n = 3$ | $t$ | $p$-values |
|---|---|---|---|---|
| Equilibrium score | | | | |
| Condition 1 | 92.83 ± 2.43 | 88.78 ± 3.02 | 2.266 | .053 |
| **Condition 2** | **91.40 ± 5.88** | **81.11 ± 2.69** | **2.830** | **.022** |
| Condition 3 | 89.62 ± 8.33 | 75.56 ± 19.57 | 1.676 | .132 |
| Condition 4 | 74.50 ± 18.65 | 46.89 ± 18.44 | 2.152 | .064 |
| Condition 5 | 61.57 ± 14.00 | 34.56 ± 30.26 | 2.019 | .078 |
| Condition 6 | 56.38 ± 12.50 | 33.00 ± 28.83 | 1.351 | .293 |
| Strategy score | | | | |
| **Condition 1** | **95.98 ± 1.08** | **94.33 ± 0.33** | **2.502** | **.037** |
| **Condition 2** | **95.21 ± 1.38** | **91.67 ± 1.15** | **3.881** | **.005** |
| Condition 3 | 94.71 ± 1.79 | 87.89 ± 11.74 | 1.002 | .420 |
| **Condition 4** | **84.90 ± 4.33** | **77.33 ± 4.81** | **2.464** | **.039** |
| Condition 5 | 74.76 ± 14.05 | 78.89 ± 8.83 | −0.462 | .656 |
| Condition 6 | 78.33 ± 5.47 | 79.00 ± 11.05 | −0.133 | .898 |
| Sensory ratio analysis | | | | |
| Composite | 71.00 ± 10.89 | 51.67 ± 19.66 | 2.140 | .061 |
| Somatosensory | 97.38 ± 5.04 | 91.67 ± 1.53 | 1.872 | .094 |
| Visual | 79.25 ± 18.71 | 52.33 ± 28.73 | 1.862 | .095 |
| Vestibular | 60.00 ± 22.31 | 38.00 ± 33.29 | 1.291 | .229 |
| Visual preference | 92.63 ± 5.24 | 90.00 ± 19.92 | 0.225 | .842 |

*Note*: Bold indicates $p<0.05$.

**TABLE 6** Imaging assessments of Meniere's disease.

| Assessments | MD ($n = 20$) |
|---|---|
| Gd-MRI | $n = 12$ |
| None | 4 (33.3%) |
| Mild endolymphatic hydrops | 3 (25.0%) |
| Significant endolymphatic hydrops | 5 (41.7%) |
| Temporal bone HRCT | $n = 12$ |
| None | 4 (33.3%) |
| Inner ear malformation | 0 (0%) |
| Enlarged vestibular aqueduct | 0 (0%) |
| Third window | 0 (0%) |
| A high jugular bulb and/or anterior sigmoid sinus | 8 (66.7%) |
| Cranial MRI | $n = 7$ |
| None | 6 (85.7%) |
| Arachnoid cyst | 1 (14.3%) |
| Abnormal enhancement signal | 0 (0%) |

*Note*: Not all the children completed all the auditory–vestibular evaluation.
Abbreviations: Gd-MRI, gadolinium contrast-enhanced magnetic resonance imaging; HRCT, high-resolution computed tomography.

vestibular information inputs to that of RVC, but the ability for the nerve center to use these clues to maintain balance is worse in MD. Since we chose sex- and age-matched adolescents as controls, it can be assumed that the difference in balance ability is mainly attributable to the disease itself rather than the influence of development. Thus, we should pay attention to not only peripheral vestibular impairment, but also central sensory integration in adolescents with MD. A few studies revealed central alterations in MD,[17,18] but limited evidence makes it difficult to discern whether it is a secondary result or a cause of the disease. Recent research has shown that maintaining posture requires attention and interacts with other common tasks that share cognitive resources. It has been observed that the increased listening effort due to hearing impairment utilizes additional attentional resources, thereby reducing the attentional resources available for posture control and increasing the risk of positional or situational instability.[19,20]

Bilateral MD causes decreased vestibular function in both sides, meaning less reliable vestibular input than unilateral MD. The current study found that bilateral MD was associated with worse balance scores and more usage of the hip strategy for balance and showed worse postural control than unilateral MD. In addition to correlation analysis, we tried to conduct difference analysis. However, due to the small sample size, the analysis of differences between groups is for reference only. In terms of trends, the averages of comprehensive scores, proprioceptive, visual, and vestibular weight scores of unilateral MD were higher than those of bilateral MD. This suggests potential differences in vestibular weights in adolescents with unilateral and bilateral MD, also potential effects on vision and proprioception. The interaction between vestibular system and other sensory system supports this argument.[21,22] It is needs to be further studied whether the interaction between multiple senses is different in unilateral and bilateral MD. Considering the characteristics of adolescents, it is also

**TABLE 7** Correlation between Gd-MRI and audiovestibular evaluation.

| Variables | Spearman correlation, $n = 12$ | *p*-values |
|---|---|---|
| Pure tone audiometry (dB HL) | .487 | .108 |
| Speech discrimination score (%) | −.359 | .429 |
| **ABR threshold (dB nHL)** | **.850** | **.007** |
| SP/AP | .372 | .468 |
| **Otoacoustic emission** | **−.976** | **<.001** |
| Video head impulse test | | |
| Anterior | .084 | .805 |
| Horizontal | −.389 | .238 |
| Posterior | −.051 | .882 |
| UW (%) | .258 | .502 |
| cVEMP (abnormal) | −.239 | .478 |
| oVEMP (abnormal) | −.222 | .513 |

*Note*: Bold indicates $p<0.05$.
Abbreviations: ABR, auditory brainstem response; cVEMP, cervical vestibular evoked myogenic potential; Gd-MRI, gadolinium contrast-enhanced magnetic resonance imaging; oVEMP, ocular vestibular evoked myogenic potential; SP/AP, summating potential/action potential; UW, unilateral warmth.

worth noting if bilateral MD and unilateral MD have different effects on visual and proprioceptive development.

### 4.3 | Imaging assessment of adolescents with MD

Vertigo in adolescents may be of congenital or hereditary origin. Therefore, CT of the temporal bone is essential to exclude the embryopathic anomalies, that is, enlarged vestibular aqueduct, Mondini anomaly, and so forth, which may induce secondary EH formation.[23,24] No inner ear malformations or enlarged vestibular aqueduct were found in the patients included in the current study. Additionally, infection or injury to the ear/brain has also been associated with high prevalence of secondary hydrops.[25] MRI could detect EH. It is not uncommon for congenital Cytomegalovirus patients, even with isolated inner ear involvement and normal brain MRI, to present with a hydrops-like picture, which is likely due to postinfectious hydrops, Therefore, the diagnosis of MD of children should take this into account.[26,27] In the current study, central vertigo was excluded by craniocerebral MRI. Gd-MRI provide information for assessing an EH and for abnormal enhanced signal in the inner ear. Our study found no infection or abnormal absent signal. The data showed that the worse the hearing, the more significant the hydrops is. Previous study reported a significant positive correlation between hearing thresholds and the grades of the EH in the cochlea and vestibule, which is consistent with our studies.[28] Although OAEs are often used to assess outer hair cell damage, it has also been found as an objective evidence for intralabyrinthine pressure disturbance in MD.[29] The current data revealed that the adolescents with MD who have failed OAE have more significant hydrops, which might be attributed to both damage and pressure.

It is important to note that the pathophysiology of MD in adolescents may differ from that of adults. However, given the lack of widely accepted diagnostic criteria for pediatric MD, we used adult criteria as a starting point for retrospective analysis. Future studies need to pay attention to the heterogeneity of the pediatric/adolescent MD population and the adult population.

Furthermore, constrained by the sample size, the statistical power of this study may be insufficient, potentially resulting in the failure to fully reveal potential differences or effects, which to some extent limits our interpretation of the research results.

## 5 | CONCLUSION

Adolescents with MD have similar vestibular information inputs with that of RVC, but the ability for the nerve center to use these clues to maintain balance is worse in adolescents with MD. There were potential differences in vestibular weights in adolescents with unilateral and bilateral MD, also potential effects on vision and proprioception.


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### CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

### DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the Supporting Information, and further inquiries can be directed to the corresponding authors.


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## SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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