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Вертикальная стойка при надевании головного убора у лиц с двусторонней вестибулярной гипофункцией: возможное участие эгоцентрической вертикали

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Аннотация. Мужчина 66 лет (испытуемый S1) с двусторонней вестибулярной гипофункцией (ДВГ) при отоневрологическом обследовании сообщил, что способен уверенно ходить и управлять автомобилем только тогда, когда надета «любимая» (с его слов) шапка. Чтобы проверить достоверность этого феномена, была оценена функция равновесия у этого пациента, а также у группы других лиц с ДВГ (n = 9) и группы молодых здоровых испытуемых (n = 23, 20–21 год, МЗ) с помощью компьютерной стабилометрии в четырех условиях вертикальной стойки: 1) с открытыми глазами на твердой поверхности (ОТ); 2) с закрытыми глазами на твердой поверхности (ЗТ); 3) с открытыми глазами на слое поролона (ОП); 4) с закрытыми глазами на слое поролона (ЗП); в условиях относительно головного убора: 1) «в головном уборе» и 2) «без головного убора». Дважды проведенное обследование испытуемого S1 показало, что в таких «сложных» условиях, как ОП и ЗП, длина и площадь эллипса траектории общего центра давления (ОЦД) действительно уменьшались при надевании его привычной («любимой») шапки. В состоянии «в головном уборе» длина траектории ОЦД уменьшилась в группах ДВГ и МЗ в условиях ЗП и ОП ($p < 0,05$), а в группе ДВГ в состоянии ЗП уменьшалась и площадь эллипса ОЦД ($p < 0,05$). Таким образом, феномен лучшего равновесия при надевании головного убора был верифицирован для сложных условий стояния (на мягкой поверхности), как в группе ДВГ, так и у здоровых испытуемых. В основе этого феномена может лежать механизм усиления «эгоцентрической» («соматосенсорной») оси отсчета (вертикали) между головой и подошвами стоп.

Ключевые слова: двусторонняя вестибулярная гипофункция, стабилометрия, равновесие тела, головной убор, эгоцентрическая вертикаль, проба Ромберга

Vertical stance in 'no-hat' vs. 'in-a-hat' conditions in subjects with bilateral vestibular hypofunction: Probable inference of the egocentric vertical

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Abstract. During a clinical otoneurological examination, a 66-year-old male subject (S1) with bilateral vestibular hypofunction (BVH) reported that he could walk confident and drive his car only while wearing his 'favorite' hat. To obtain evidence in support of his claim, we conducted a stabilometric analysis on the subject S1, a group of other BVH patients (n = 9), and a group of healthy young subjects (n = 23, aged 20–21, HY) under four standing conditions: (1) eyes open on a solid surface (EOS), (2) eyes closed on a solid surface (ECS), (3) eyes open on foam rubber (EOF), and (4) eyes closed on foam rubber (ECF). The subjects were also tested in two headwear conditions: (1) 'in-a-hat' and (2) 'no-hat'. Our findings revealed that under challenging conditions (EOF, ECF), the length and ellipse area of the center of pressure (CoP) trajectory were significantly reduced when the subject wore a hat. This effect was not observed under simpler conditions (EOS, ECS). In the 'in-a-hat' condition, both BVH and HY subjects exhibited shorter CoP trajectory lengths in EOF and ECF conditions ($p < 0.05$). Additionally, the CoP ellipse area decreased in the BVH group. These results suggest that the phenomenon of improved stance with a hat may be linked to the emergence of an egocentric (somatosensory) vertical reference axis between the head and feet.

Keywords: bilateral vestibular hypofunction, stabilometry, body balance, headwear, egocentric reference, Romberg's test

Introduction

Human body balance is maintained through the integration of vestibular, visual, and proprioceptive sensory systems (Foisy, Kapoula 2018). These systems organize gravicentric, allocentric, and egocentric coordinate or reference systems, respectively. The gravicentric system determines the gravitational vertical, a sense of balance and spatial orientation, underpinning the ability to distinguish between movements of the body and external objects (Foisy, Kapoula 2018; Mittelstaedt 1999). The allocentric system establishes the visual vertical, which enables spatial awareness and the assessment of distances to objects (Lopez et al. 2007). The egocentric system provides information on joint position, movement, and inertia (Anastasopoulos et al. 1999; Foisy, Kapoula 2018). For effective spatial orientation and movement, these systems work together, though their relative contributions to balance can vary. Factors such as surface inclination and eye closure can modify the 'weighting' of each system (Feller et al. 2019), particularly in older adults, who tend to rely more on visual cues than proprioceptive references compared to younger individuals (Jaime 2014; Peterka 2002). Vestibular input generally remains intact in older populations and in individuals with Parkinson's disease (Smith 2018).

In contrast, patients with bilateral vestibular hypofunction (BVH), where vestibular function is significantly diminished or absent bilaterally, rely more heavily on visual cues, often developing a condition referred to as 'visual dependence', which manifests as increased unsteadiness in low-visibility environments (darkness, twilight). On average, BVH occurs in 3.6% of individuals who complain of vertigo or dizziness (Grill et al. 2018).

In early 2023, during a routine medical visit, we examined a 66-year-old man with BVH (S1) who claimed that he could 'confidently walk and drive' only when wearing his 'favorite' hat. This cap has a tight fit and features a visor (Fig. 1, middle panel). According to the patient, he feels better oriented spatially when wearing the hat, which he believes helps him 'perceive' his position in space. We hypothesized that the patient, in addition to visual cues (allocentric), might need a tactile (somatosensory) vertical reference between his head and feet. In his case, this vertical is established through somatosensory (proprioceptive/tactile) stimulation of the head (a tight-fitting hat) and feet (support from soles of the feet). The concept of the 'motor vertical' or 'haptic vertical' has been previously discussed in the literature (Bury, Bock 2018; Cléement et al. 2007). In addition, previous studies also discuss a 'sensory fusion' of the three sensory systems (Delle Monache et al. 2023; Vingerhoets et al. 2009; Wright et al. 2005; Yamamoto, Yamamoto 2006).

To test our hypothesis (the 'favorite hat' phenomenon) and validate S1's subjective experiences, we performed stabilometric assessments of vertical stance under various sensory conditions (with eyes open and closed (the Rombert test), standing on a hard surface or foam rubber), both with and without the hat. We also included additional BVH patients and healthy young subjects to compare the results across groups.

Materials and methods

Case report: Subject S1

Over the past two years, the subject, a 66-year-old man, has complained of severe instability, spatial imbalance, and a sensation of 'swaying of the surrounding visual environment in the vertical plane' when walking. However, he has never complained of dizziness. The subject was treated with antibacterial drugs for coronavirus infection (Covid-19) and associated his complaints about postural instability with Covid-19. The subject cannot remember the name of the drug and his medical records are missing because the subject is a foreign resident. Additionally, he noted significant bilateral hearing loss over the past three years. The subject has hypertension (stage II, risk stage I) and is on antihypertensive therapy with the target blood pressure of 120/80 mm Hg. He denied any other chronic somatic, neurological, or orthopedic conditions and allergies to drugs. Notably, he claimed to walk unassisted and drive a car only when wearing his 'favorite' hat — a tight-fitting baseball cap with a visor (Fig. 1).

Before the study, the subject (S1) underwent general clinical, otolaryngological, and otoneurological examination. The audiologist diagnosed bilateral chronic sensorineural hearing loss. The following audiometric data were obtained: whisper AD/AS 1.5/2.0 meters, regular speaking AD/AS 6.0/6.0 meters (normal). Non-contrast magnetic resonance imaging of the brain and endoscopy of the digestive tract did not reveal any pathology. Vestibulometry revealed (1) absent spontaneous oculomotor responses; (2) normal slow gaze tracking; (3) normometric saccades; (4) bilateral positive Halmagyi-Curthoys Head Impulse Test (Rajamani et al. 2024); (5) pronounced unsteadiness without vectoriality in the Romberg test; (6) inability to perform the Fukuda-Unterberger Stepping Test (repetitive walking on the spot while blindfolded) (Hemm et al. 2023); (7) accurate finger touch tests; (8) pronounced unsteadiness when walking with eyes open; (9) inability to walk with eyes closed. Based on these data, the bilateral vestibular hypofunction (BVH) was diagnosed.

Subjects

The BVH group included 9 subjects (6 females, 3 males), diagnosed with BVH following standard otolaryngological and otoneurological evaluations. In all patients, BVH was confirmed through bithermal caloric testing, with a slow-phase nystagmus velocity no greater than 6 °/s bilaterally. In three patients, BVH developed as a result of ototoxic drug use — aminoglycoside antibiotic (two patients) and chemotherapy (one patient). One patient associated the development of BVH with therapy of new coronavirus COVID-19 infection (the name of the drug was not found). One patient had bilateral Meniere's disease in the final stage, and one patient had a history of an autoimmune disease (Wegener's disease). In the remaining patients, the cause of BVH was considered idiopathic. None of the BVH subjects reported improved balance while wearing a hat.

Fig. 1. Left panel — S1 without a hat; middle panel — S1 with his 'favorite' hat on;
right panel — a young healthy subject in a fur winter hat (photo by E. N. Kravtsova, 2022)

The healthy young group (HY) included 23 subjects (15 females, 8 males) aged 20–31 years, with no otological, neurological, or orthopedic conditions. Informed consent was obtained from all the subjects, and the study was approved by the Joint Committee for Medical Ethics of the Ministry of Health Care of the Republic of Karelia and Petrozavodsk State University (approval No 34 dated 22 April 2015). The anthropometric data on the studied groups is summarized in Table 1.

Videonystagmography

Before the study, all the subjects underwent videonystagmography (VNG) (Moideen et al. 2023). It is a pupil motion video capture technology during caloric testing (VNG, Intracustic A/S, Denmark). In BVH subjects, spontaneous cervical nystagmus was not observed. During bithermal caloric testing, the mean velocity of the slower phase of nystagmus ranged from 3 to 4 °/s, which reliably confirmed the diagnosis of BVH. In contrast, healthy young subjects exhibited clear nystagmus in response to both cold (30 °C air) and warm (44 °C air) caloric stimuli, producing a characteristic 'butterfly' pattern (Fig. 2).

Computer-based stabilometry

Standing conditions. The stability of stance was assessed using ST150 force stabilometric plate (MERA, Moscow, Russia). Stabilometry was performed in an upright 'European stance' (heels together, toes apart) under four different standing conditions: (1) eyes open on a solid surface (EOS); (2) eyes closed on a solid surface (ECS, the Romberg test); (3) eyes open on 15 cm thick foam rubber (EOF, the Foot Reaction Test); (4) eyes closed on foam rubber (ECF) (Meigal et al. 2021). The EOS condition was considered a simple sensory condition (Forbes et al. 2018), reflecting typical everyday circumstances. The other conditions (ECS, EOF, and ECF) were categorized as complex sensory conditions, with ECF being the most complex due to the combined loss of vision and reduced proprioceptive feedback from the soles of the feet (Meigal et al. 2021).

Headwear conditions. In each of the four standing conditions, the trajectory length (L, mm) and 95% confidence ellipse area (S, mm^2) of the common center of pressure (CoP) was recorded. During stabilometric testing, S1 wore his 'favorite' tight-

Table 1. Anthropometric characteristics of the studied groups

Group	Age (years)	Height (cm)	Weight (kg)	BMI
BVH	63.4 ± 10.2	166.7 ± 13.7	80.2 ± 20.3	28.7 ± 5.6
HY	23.3 ± 3.1	170.8 ± 9.3	68.3 ± 12.5	23.4 ± 3.8

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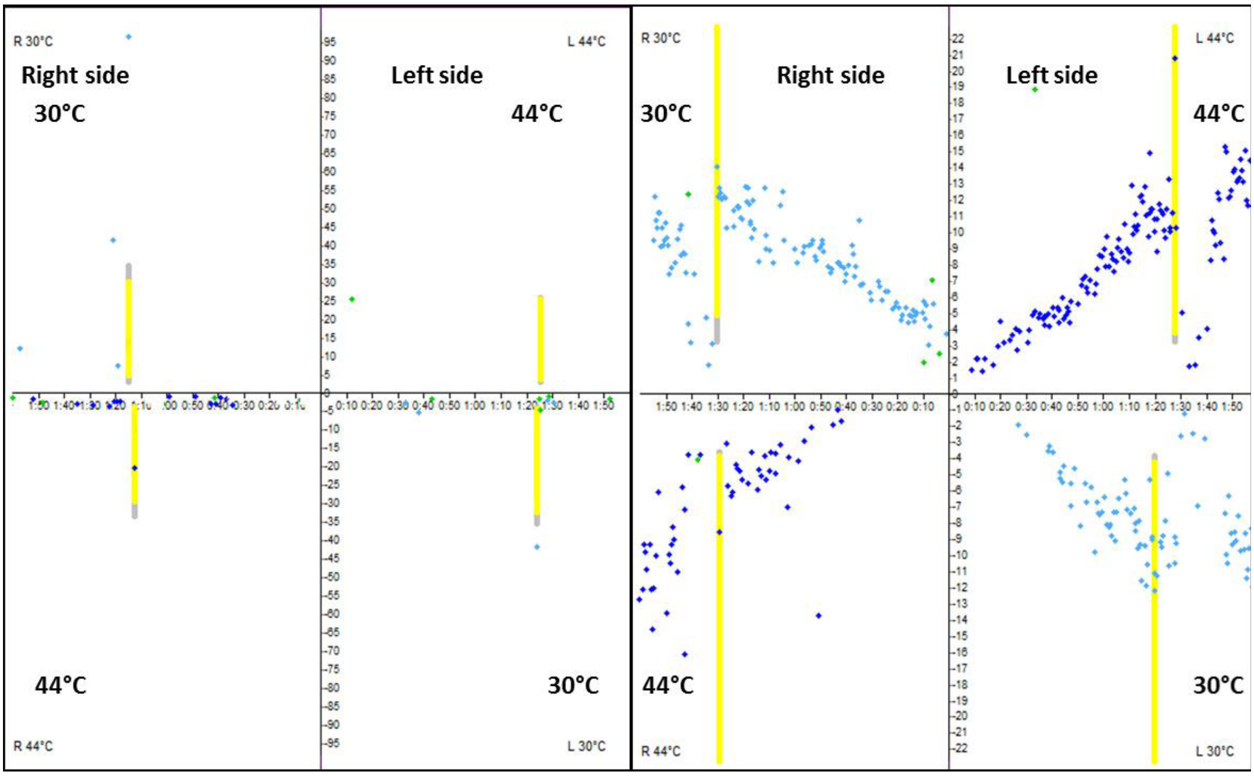

Fig. 2. Videonystagmograms of the subject with BVH (left panel) and a representative healthy young subject (right panel). In the healthy subject (right panel), eye movements are directed toward the warm stimulus (dark blue dots, 44 °C air) and in the opposite direction from the cold stimulus (light blue dots, 30 °C air), symmetrically. In contrast, the left panel shows no reaction to caloric stimuli. The yellow vertical bars indicate a sudden light flash stimulus, after which, in normal subjects, the eyes cease to deviate in response to the caloric stimuli for several seconds (right image)

fitting cap with a visor (Fig. 1). This study was conducted under two conditions: 'in-a-hat' and 'no-hat' twice, with a six months interval between measurements. Similarly, the BVH and HY groups underwent stabilometry under the same standing and headwear conditions, with the visor cap replaced by a fur winter hat weighing approximately 200 g (see Fig. 1B).

Statistics

A comparison between the 'in-a-hat' and 'no-hat' conditions was performed using the Wilcoxon test (IBM SPSS Statistics 21.0, SPSS, IBM Corporation, Chicago, IL, USA).

Results

The stabilometric characteristics of the subject with BVH (S1) are presented in Table 2. The length of the CoP trajectory is shown across four standing conditions on a force platform and two headwear conditions — 'no-hat' and 'in-a-hat'. Under regular (simple) standing conditions (EOS), the difference between the headwear conditions was negligible. However, when vision and/or proprioception from the soles were deprived, the CoP trajectory was notably shorter in the 'in-a-hat' condition. A similar pattern was observed for the CoP ellipse area (see Table 2).

In the group of young healthy controls, a similar trend was observed regarding the CoP trajectory — it increased with the progression of more challenging conditions from standing with eyes open on a firm surface to standing with eyes closed on foam rubber (Table 3). Wearing a hat resulted in a shortening of the CoP trajectory in EOF and ECF conditions, i. e., in the most challenging tasks. However, this effect was not observed for the CoP ellipse area (Table 4).

Discussion

The original research question was to empirically test the claim of a subject with BVH that wearing a hat significantly improved his ability to maintain an upright posture and walk. We hypothesized that wearing a hat may help establish or reinforce the proprioceptive ('egocentric' or internal) vertical between the soles of the feet and the head, thereby enhancing body balance. To test

Table 2. Trajectory length and ellipse area of CoP in S1 with BVH under different standing and headwear conditions

Condition	EOS	ECS	EOF	ECF
First trial, the trajectory length (mm)				
no-hat	531	1.955	898	3.042
in-a-hat	516	1.220	659	2.939
Second trial, the trajectory length (mm)				
no-hat	361	1.069	1.186	2.819
in-a-hat	394	861	921	1.991
First trial, 95% confidence ellipse square (mm^2)				
no-hat	460	3.890	1.358	8.001
in-a-hat	460	1.549	562	5.441
Second trial, 95% confidence ellipse square (mm^2)				
no-hat	633	2.302	1.117	7.584
in-a-hat	232	1.368	661	5.291

Table 3. Trajectory length and ellipse area of CoP in the BVH group under different standing and headwear conditions

Condition	EOS	ECS	EOF	ECF
The trajectory length (mm)				
no-hat	445 ± 145	1061 ± 691	1.104 ± 543	2.267 ± 2.938
in-a-hat	440 ± 128	942 ± 576	440 ± 128	942 ± 576**
Wilcoxon Signed Ranks test, p	0.635	0.086	0.028	0.046
95% confidence ellipse area (mm^2)				
no-hat	533 ± 678	1.699 ± 115	1.159 ± 108	4.189 ± 623
in-a-hat	447 ± 596	1.266 ± 328	1.005 ± 963	2.995 ± 817**
Wilcoxon test, p	0.401	0.110	0.139	0.038

Table 4. Trajectory length and ellipse area of CoP in the young and healthy control group under different standing and headwear conditions

Condition	EOS	ECS	EOF	ECF
The trajectory length (mm)				
no-hat	213 ± 54	320 ± 91	448 ± 249	1.004 ± 404
in-a-hat	241 ± 64	329 ± 106	369 ± 73*	900 ± 266**
Wilcoxon test, p	0.126	0.664	0.027	0.013
95% confidence ellipse area (mm^2)				
no-hat	131 ± 115	175 ± 115	200 ± 108	827 ± 623
in-a-hat	151 ± 85	213 ± 128	271 ± 273	763 ± 317
Wilcoxon test, p	0.278	0.485	0.196	0.979

this hypothesis, we conducted a study involving this subject, as well as a group of individuals with BVH and a group of healthy young adults. All participants were tested under four standing conditions (eyes open, eyes closed, standing on a solid or foam surface, or both) and two headwear conditions — wearing a hat and without a hat — using computer-assisted stabilometry. We hypothesized that wearing a hat would improve upright posture in both the subject with BVH and healthy young adults.

Repeated examination of the subject with BVH showed that under challenging conditions (standing on foam rubber with eyes closed or open), both the length and the ellipse area of the CoP trajectory significantly reduced *when the hat was on*. However, under standard conditions (staying on a hard surface with eyes open) this effect was not observed.

Similarly, in both the BVH group and a group of healthy young adults, wearing a hat resulted in greater stability during standing under challenging conditions (standing on foam rubber with eyes closed or open). Taken together, these findings suggest that wearing a hat may have positively influenced the stability of a vertical stance, as evidenced by a reduction in CoP trajectory length and, to a lesser degree, the 95% confidence ellipse area under the most challenging conditions (standing on a soft foam surface with eyes closed).

To date, we have found no studies in the existing scientific literature investigating the effect of wearing a headdress on an individual's vertical stance or walking. However, several studies have demonstrated that tactile stimuli ('tactile tips') can significantly improve awareness of *peripersonal* space and spatial orientation when eyes are closed (D'Angelo et al. 2018; Gurfinkel et al. 1993; Holmes, Spence 2004).

Provisionaly, we have referred to the enhanced stability observed when wearing a hat as the 'favorite hat' phenomenon. To some extent, this phenomenon in both healthy individuals and those with BVH can be considered within the framework of concepts such as 'peripersonal space', 'body schema', and the 'system of internal representations' (D'Angelo et al. 2018; Holmes, Spence 2004; Levik 2021).

Physically, a headdress has weight (typically several hundred grams) and, as such, exhibits inertia when the head moves. Furthermore, a close fit of the headdress on the head, with tight contact to the scalp, may mechanically stimulate cutaneous receptors and subcutaneous proprioceptors.

In the standing position, during a vertical stance, the soles of the feet are stimulated by the supporting surface ('supporting afferents'). Thus, the simultaneous stimulation of proprioceptors at two opposite extremities of the body — the head and the soles of the feet — may contribute to the establishment of a proprioceptive (or 'egocentric') vertical, complementing the gravicentric and visual ('allocentric') vertical.

This is consistent with earlier studies highlining the significance of the 'longitudinal' or 'motor' vertical in standing (Bury, Bock 2018; Clément et al. 2007) and 'haptic vertical' (Fraser et al. 2015). Under the most challenging standing conditions (standing on a soft foam surface with eyes closed or open), this 'proprioceptive' vertical may provide additional information about the body's spatial orientation, similar to the 'tactile tips' described by Gurfinkel (Gurfinkel et al. 1993) and Levik (Levik 2021).

Thus, the mechanism underlying the effect of wearing a hat during upright stance may involve the enhancement of the 'longitudinal' body axis from the soles of the feet to the head through the stimulation of head exteroceptors (skin) and proprioceptors (scalp).

Limitations to the study and future studies

A limitation of this study pertains to the variability in headgear worn by the subjects. Specifically, S1 wore his 'favorite' hat (a visor cap) that was not available for use by the other study participants, as S1 wears the hat literally all the time and resides in a different country. Additionally, the visor cap did not fit all of the other subjects in the study. Consequently, a fur winter hat was chosen for the remaining participants, as it was deemed the most suitable alternative.

Conclusion

In the present study, the claim made by an individual with bilateral vestibular hypofunction that wearing a hat enhances his spatial orientation and walking efficiency was experimentally validated. This phenomenon was also observed in a group of BVH patients and a group of healthy young adults. We hypothesized that the 'in-a-hat phenomenon' may be attributable to mechanisms that strengthen the egocentric internal reference or the body's longitudinal axis, ultimately influencing the internal representation system.

Конфликт интересов

Авторы заявляют об отсутствии конфликта интересов

Conflict of Interest

The authors declare that there is no conflict of interest.

Соответствие принципам этики

Перед началом исследования все участники получили объяснение процедуры и рисков, с которыми впоследствии придется столкнуться при их участии, и предоставили информированное согласие на участие в этом исследовании. Исследование одобрено Объединенным комитетом по медицинской этике Министерства здравоохранения Республики Карелия и Петрозаводского государственного университета № 34 от 22 апреля 2015 г., все процедуры проведены в соответствии с Хельсинкской декларацией.

Ethics Approval

Prior to the commencement of the study, all participants were thoroughly briefed on the procedure and potential risks associated with their involvement, and they provided informed consent to participate in the study. The study was approved by the Joint Committee for Medical Ethics of the Ministry of Health Care of the Republic of Karelia and Petrozavodsk State University (approval No 34 dated 22 April 2015). All the procedures were conducted in accordance with the Declaration of Helsinki.

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