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ORIGINAL ARTICLE

# Saccadic entropy of head impulses in acute unilateral vestibular loss

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**KEYWORDS**
acute vestibular loss;
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saccadic entropy

*Background/Purpose:* To evaluate the complexity of vestibular–ocular reflex (VOR) in patients with acute unilateral vestibular loss (AUVL) via entropy analysis of head impulses.
*Methods:* Horizontal head impulse test (HIT) with high-velocity alternating directions was used to evaluate 12 participants with AUVL and 16 healthy volunteers. Wireless electro-oculography and electronic gyrometry were used to acquire eye positional signals and head velocity signals. The eye velocity signals were then obtained through differentiation, band-pass filtering. The approximate entropy of eye velocity to head velocity ($R_{ApEn}$) was used to evaluate chaos property. VOR gain, gain asymmetry ratio, and $R_{ApEn}$ asymmetry ratio were also used to compare the groups.
*Results:* For the lesion-side HIT of the patient group, the mean VOR gain was significantly lower and the mean $R_{ApEn}$ was significantly greater compared with both nonlesion-side HIT and healthy controls ($p < 0.01$, one-way analysis of variance). Both the $R_{ApEn}$ asymmetry ratio and gain asymmetry ratio of the AUVL group were significantly greater compared with those of the control group ($p < 0.05$, independent sample $t$ test).
*Conclusion:* Entropy and gain analysis of HIT using wireless electro-oculography system could be used to detect the VOR dysfunctions of AUVL and may become effective methods for evaluating vestibular disorders.


*Abbreviations:* AAR, ApEn asymmetric ratio; ApEn, approximate entropy; GAR, gain asymmetric ratio; HIT, head impulse test; VOR, vestibular–ocular reflex.

Conflicts of interest: The authors have no conflicts of interest relevant to this article.

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## Introduction

The head impulse test (HIT) is a useful bedside examination that enables identifying the side of peripheral vestibular hypofunction.[1–3] The head impulses used in the testing are rapid and passive head rotations with unpredictable directions. For an HIT test, a patient is requested to visualize a stationary target and fixate on it while the examiner turns the patient's head in the plane of pairs of semicircular canals. If the peripheral vestibular system is intact and the vestibular–ocular pathway operates normally, the patient's eye can remain fixed on the target. If not, covert and overt correcting saccades may be detected during and after head turn to the side of the lesion. Covert saccades are usually not easy to observe using the naked eyes of the examiner and can confound the HIT assessment.

Acute vestibular syndrome (AVS) is a syndrome of new onset, continuous vertigo that lasts for days to weeks, accompanied by nausea and vomiting, motion intolerance, and unsteady gait.[4] Among patients with AVS, vestibular neuritis is the most common cause, followed by posterior fossa ischemic stroke.[4,5] Differentiation between the two clinical conditions is crucial and challenging for a clinical physician. According to a literature review, the horizontal HIT is an effective bedside predictor of peripheral versus central causes of AVS.[2] A unilaterally abnormal HIT performance was identified in approximately 95% of patients with vestibular neuritis,[4] whereas less than 10% of stroke patients presented with an abnormal HIT.[6] An abnormal presentation of horizontal HIT typically indicates a dysfunction of vestibular–ocular reflex (VOR) and thus suggests a peripheral vestibular lesion. However, a normal HIT in AVS usually implies a stroke. A noninvasive three-step oculomotor test battery, represented by the acronym HINTS (head impulse, nystagmus, test of skew) was reported to have a sensitivity of 100% and a specificity of 96% for stroke.[7] Moreover, HIT is usually performed by experienced neuro-otologists, and the sensitivity was significantly lower than that performed by nonexperts because of a prudent preference of false negative result.[3] However, bedside HIT has several limitations. First, VOR gain and corrective saccades cannot be measured objectively. Second, covert saccades occurring during head turns are easily missed. Third, only a few head turns are performed, and a range of stimuli that generate a stimulus-response function are thus not tested. All these factors may limit the generalizability of bedside HIT. Currently, there are several sensitive techniques to measure the ocular movements in HIT such as scleral search coil[8,9] and infrared video recording system.[10] These systems can sensitively detect VOR deficits such as overt and covert saccades in patients with peripheral vestibulopathies. However, the search coil system is more expensive, somewhat invasive (it requires the examinee to wear contact lenses), and clinically typically unavailable at present time. There are several commercially available video-HIT systems, and many dizzy centers have adopted this test. The video-HIT system has revealed its efficacy in identifying peripheral vestibular deficits.[10] Traditionally, the electro-oculography (EOG) system is used to evaluate optokinetic and vestibular systems for a long time with the advantages of detection of eye movements under closed eyelids and high-frequency continuous sampling that facilitates detection of high-velocity movements. However, the system is not commonly used in HIT.

Neuronal activity is generated by a composite deterministic system with some stochastic input, and the neural system usually has both linear and nonlinear characteristics. The complexity and nonlinear characteristics of the neural system can be evaluated using chaotic analysis, and the approximate entropy (ApEn) is a typical example that was used in the research on heart rate variability[11] and cardiac pacemaker activity.[12] However, a disordered neural system may increase its chaotic property and may be evaluated using the entropy analysis as well.

In this research, we enrolled both healthy volunteers and patients with acute peripheral vestibular loss. With wireless EOG, entropy analysis of HIT was applied to evaluate the function and complexity of VOR. The objective assessments using the new methodology are revealed, and the accuracy of the subjective assessment is also presented.

## Materials and methods

### Participants

Twelve patients (8 women, 4 men; age 27–59 years, with a median of 46 years) presenting with vertigo due to acute unilateral vestibular loss (AUVL) were enrolled from the department of otolaryngology of a tertiary referral hospital between November 2014 and December 2015. The patients with acute vertigo, accompanied by either spontaneous nystagmus or gaze-evoked nystagmus that fulfilled Alexander's law and was confirmed with videonystagmography, were included. Caloric test was performed in nine patients, and eight of them revealed the abnormal responses of unilateral weakness $>25\%$ ($n = 5$) or directional preponderance $>30\%$ ($n = 3$). The HIT was performed for all patients within 2 to 7 days after the first symptom was felt. Eight patients were diagnosed with vestibular neuritis and two patients were diagnosed to have unilateral sudden loss of vestibular and cochlear functions. One case was Ramsay Hunt syndrome, and the last patient had right middle ear cholesteatoma with labyrinthitis. Sixteen healthy participants (9 women, 7 men; ages 24–63 years, with a median of 38 years), having no history of vertigo, hearing loss, ear surgery, head surgery, were enrolled as the control group. All participants reported no visual disturbances, oculomotor diseases, cervical spine disorders, or psychiatric diseases. Written informed consent was obtained from all participants, and the research protocol was approved by the institutional review board (IRB# 11MMHIS131).

### Hardware settings

A small and light sensor ($5 \times 2 \times 1$ cm in size and less than 20 g in weight) was fixed at the vertex of the head with a headband.[13] Two horizontal electrodes were placed at the outer canthi of the eyes. The sensor consisted of a two-axis electronic gyrometer (LPY550AL, STMicroelectronics, maximal angular velocity 2000°/s, sensitivity 0.5 m/°/s V)