

Stabilometry in Sports Medicine & Doping Studies

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Background and Objective

Sports and/or doping are effective as a countermeasure for a broad range of problems in our daily lives. A countermeasure enables a recovery from some dysfunction or deconditioning such as temporary nearsightedness or space flight deconditioning. These two problems are outlined as follows.

Myopia

With the development of computers and the widespread use of the internet, an increasing number of people perform near-visual tasks such as operations on Video Display Terminals (VDTs). Working under these conditions for several hours induces contraction of the ciliary muscles, which are involved in focus adjustment around the eyeball. These muscles can abnormally contract as a result of the long-term performance of a near-visual task. This contraction causes various vision problems such as asthenopia and visual loss, and has been reported to induce cervicobrachial and psychoneurotic syndromes [1,2]. An accommodative function error of the lens causes these vision problems, which can be improved or prevented from progressing via ciliary muscle stretching exercises. These exercises can be performed by alternately repeating the negative and positive accommodations of the eye.

Some studies examined the effect of the operation of muscle activation, which is called accommodation training. For this, eyesight recovery and training apparatus (MD-SS type) was developed, which moves a Landolt ring drawn on a flat plate 2 m back and forth to encourage alternating negative and positive accommodation in the observers [3]. However, the moving distance of the target object is very short. Therefore, the back-and-forth motion of the objects might have little effect on the observers. In order to solve this problem while also reducing the size of the apparatus, alternative accommodation training was accomplished via images in three-dimensional (3D) movies. The 3D movies simulate the back-and-forth motion in a stereoscopic space by using a computer and a Liquid Crystal Display (LCD).

For persons afflicted with pseudo myopia, performing accommodation training alleviates strain and temporarily improves the myopic condition [4,5]. However, watching 3D movies may produce adverse effects such as asthenopia and motion sickness [6]. Measuring the severity of Visually Induced Motion Sickness (VIMS) can be accomplished by using psychological and physiological methods that have not been established. Our previous studies used the following hypothesis: VIMS changes the system to control the body sway [7-9].

Space flight deconditioning

It would be possible to prevent the harmful influence of microgravity exposure ($<10^{-6}$ G) on the human body if a 1 G environment were prepared in outer space [10]. Medical problems associated with long-term (greater than six months) microgravity exposure include "space motion sickness" in the early phases of space flight; cardiovascular deconditioning, which leads to decreased orthostatic tolerance;

musculoskeletal deconditioning with atrophy, particularly in the antigravity muscles; and bone deconditioning with bone metabolism abnormalities. The general term used to describe these phenomena is "space deconditioning." Effective preventative measures for each type of deconditioning have been recommended, but comprehensive countermeasures have not been adopted.

Some devices have been developed as countermeasures using centrifuge-induced artificial gravity and ergometric exercise. Two types of devices are used to load artificial gravity: a long-arm device and a short-arm device. The former device can load 6–9 G onto subjects and is also used as a simulator for airplane pilots. However, it is difficult to load an artificial satellite or a space shuttle with a long-arm device. Therefore, the latter device, composed of a rotating rod with a diameter of 4 m that creates artificial gravity by centrifugal force and equipped with a bicycle ergometer, was created as a countermeasure against space deconditioning [11,12]. The anti-pooling function in the lower legs was significantly suppressed by a simulated microgravity exposure by using a 6° head-down bed rest, and appeared to also be counteracted by centrifugal artificial gravity and ergonomic exercise [13].

Because of large individual differences in G-tolerance, anti-G tests were performed before and after microgravity exposure [11,12]. However, the effects of applied gravity as a countermeasure and gravitational loading in anti-G tests on vestibulospinal and vestibulo-ocular functions have not been evaluated. Therefore, in our study, we evaluated the effects of artificial gravity exposure on vestibulospinal and vestibulo-ocular functions using stabilometry [14].

Solutions and recommendations

The body's balance function utilizes sensory signals such as visual, auditory, and vestibular inputs, as well as proprioceptive inputs from the skin, muscles, and joints [15]. The evaluation of this function is indispensable for diagnosing equilibrium disturbances like cerebellar degenerations, basal ganglia disorders, or Parkinson's disease [16]. Stabilometry has been employed for both qualitative and quantitative evaluations of this equilibrium function. The projection of a subject's center of gravity onto a detection stand is measured as an average of the Center of Pressure (COP) of both feet. The COP is traced for each time step, and the time series of the projections is traced onto an x-y plane. By connecting the temporally vicinal points, a stabilogram is created. Several parameters are commonly used in clinical studies to quantify the degree of instability while standing: area of sway (A), total locus length (L), and locus length per unit area (L/A). The last parameter is strongly related to the fine variations involved in posture control [17].

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Thus, the L/A index is regarded as a gauge for evaluating the function of proprioceptive control of standing. However, it is difficult to clinically diagnose balance disorders and identify a decline in equilibrium by utilizing the abovementioned indices and measuring patterns in a stabilogram. The large individual differences make it difficult to interpret the results of such a comparison.

For the data analysis, the anterior-posterior direction was considered to be independent of the lateral direction [18]. Stochastic Differential Equations (SDEs) were proposed as mathematical models to generate the stabilogram [19-21]. The variance in the stabilogram depends on the form of the temporally averaged potential function in the SDE, which generally has plural minimal points. In the vicinity of these points, local stable movement with a high-frequency component was generated as a numerical solution to the SDE. We can therefore expect a high density of observed COP in this area on the stabilogram [21]; Sparse Density (SPD) is regarded as an index for this measurement.

SPD is defined by an average of the ratio $G_j(1)/G_j(k)$ for $j=3, 4, \dots, 20$, where $G_j(k)$ is the number of divisions having more than k measured points. A stabilogram is divided into quadrants whose latus is j times longer than the resolution. If the center of gravity is stationary, the SPD value is 1. If there are variations in the stabilograms, the SPD value is greater than 1. Thus, the SPD depends on the characteristics of the stabilogram and the minimal structure of the temporally averaged potential function.

The forces acting on the center of gravity of the body are defined in terms of the differences in the displacement vectors. In particular, we focus on singular points at which statistically large forces are exerted. On the basis of these forces, chains are eliminated from the stabilogram in the form of a consecutive time series. If the times measured at these points were in the temporal vicinity, these points were connected by segments (sequences). Figures formed by these sequences are called "chains" because of the shape of the connections. The figures demonstrate that the chains at which large forces are exerted have cusp patterns.

Future research directions

These geometrical indices in stabilograms have already been calculated out of physiological curiosity to evaluate equilibrium deterioration with advancing age [22] and cerebral suppression from alcoholic intake [23,24]. However, the analytical results of the calculation of the indices can also be applied to develop devices that reduce the severity of motion sickness induced by blurred images on LCDs [7], 3D video clips [8,9], artificial gravitational loads [17], and Galvanic Vestibular Stimulation (GVS), which mask regular signals until they reach vestibular nuclei [25]. The use of GVS during simulated driving may create a highly realistic experience, supporting the contention that the application of GVS during simulations in a virtual environment reduces simulator adaptation syndrome [26]. Observation of multiple senses may assist our investigations and developments.

Why are stereoscopic images unnatural for human vision? According to a commonly accepted explanation, a certain sensory conflict causes problems while viewing stereoscopic images. A general explanation is as follows: "During stereoscopic vision, accommodation and convergence are mismatched and this is the main reason for the visual fatigue caused by 3D. During stereoscopic vision, while accommodation is fixed on the display that shows the 3D image, convergence of left and right eyes crosses at the location of the stereo image."

Patterson also provided a recent estimate of the depth of field of the human eye and shows that the accommodation-convergence conflict

would likely not occur under most stereo display viewing conditions, i.e., it might only occur when using near-eye displays [27]. The critical issue is to present the virtual images at depth planes that fall within the depth of field of the viewer, which would prevent such conflict; this would likely happen under most conditions. When the virtual image is presented within the viewer's depth of field, the accommodation can follow the convergence response without any conflict because there would be no blur signal to drive the accommodation back to the display surface. Under such conditions, it would be predicted that the viewer would accommodate at the distance of the convergence response, for which support is provided by our previous studies [28,29].

A sensory conflict between the visual and vestibular systems caused increased sway with eyes open during stabilometry after graded gravitational loading [14]. To confirm these findings, we measured eye movements using EOG in order to evaluate the vestibular nystagmus after initiation and discontinuation of centrifugal rotation. The analysis of the EOG results demonstrated the conflict between the visual and vestibular information. Next, optokinetic after-nystagmus and postrotatory nystagmus induced by the vestibulo-ocular reflex must be investigated in detail using an infrared charge-coupled device camera or Frenzel glasses. Moreover, we will examine whether the artificial gravity with ergometric exercise can be regarded as a countermeasure of space flight deconditioning in accordance with the bedrest studies.

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