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Original Research Article

# Subjective visual vertical assessment with mobile virtual reality system

Ingrida Ulozienė [a], Milda Totilienė [a,*], Andrius Paulauskas [b], Tomas Blažauskas [b], Vaidotas Marozas [c], Diego Kaski [d], Virgilijus Ulozas [a]

[a] Department of Otorhinolaryngology, Medical Academy, Lithuanian University of Health Sciences, Kaunas, Lithuania
[b] Department of Software Systems, Faculty of Informatics, Kaunas University of Technology, Lithuania
[c] Biomedical Engineering Institute, Kaunas University of Technology, Lithuania
[d] Sobell Department for Motor Control, University College London, United Kingdom

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ABSTRACT

*Background and objective:* The subjective visual vertical (SVV) is a measure of a subject's perceived verticality, and a sensitive test of vestibular dysfunction. Despite this, and consequent upon technical and logistical limitations, SVV has not entered mainstream clinical practice. The aim of the study was to develop a mobile virtual reality based system for SVV test, evaluate the suitability of different controllers and assess the system's usability in practical settings.

*Materials and methods:* In this study, we describe a novel virtual reality based system that has been developed to test SVV using integrated software and hardware, and report normative values across healthy population. Participants wore a mobile virtual reality headset in order to observe a 3D stimulus presented across separate conditions – static, dynamic and an immersive real-world (''boat in the sea'') SVV tests. The virtual reality environment was controlled by the tester using a Bluetooth connected controllers. Participants controlled the movement of a vertical arrow using either a gesture control armband or a general-purpose gamepad, to indicate perceived verticality. We wanted to compare 2 different methods for object control in the system, determine normal values and compare them with literature data, to evaluate the developed system with the help of the system usability scale questionnaire and evaluate possible virtually induced dizziness with the help of subjective visual analog scale.

*Results:* There were no statistically significant differences in SVV values during static, dynamic and virtual reality stimulus conditions, obtained using the two different controllers and the results are compared to those previously reported in the literature using alternative methodologies. The SUS scores for the system were high, with a median of 82.5 for the Myo controller and of 95.0 for the Gamepad controller, representing a statistically significant difference between the two controllers ($P < 0.01$). The median of virtual reality-induced dizziness for both devices was 0.7.

* *Corresponding author at*: Department of Otorhinolaryngology, Medical Academy, Lithuanian University of Health Sciences, Eivenių 2, 50161 Kaunas, Lithuania.
E-mail address: milda.totiliene@lsmuni.lt (M. Totilienė).
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*Conclusions:* The mobile virtual reality based system for implementation of subjective visual vertical test, is accurate and applicable in the clinical environment. The gamepad-based virtual object control method was preferred by the users. The tests were well tolerated with low dizziness scores in the majority of patients.



## 1. Introduction

The subjective visual vertical (SVV) refers to an individual's ability to indicate what he or she perceives to be an Earth vertical line, in the absence of an external reference frame. A tilt of the SVV is a sensitive sign of a vestibular tone imbalance, resulting from lesions affecting central and peripheral vestibular pathways. Peripheral pathways run from the vestibular apparatus (semicircular canals and otolith organs) to the vestibular nuclei, via the vestibular nerve, and central pathways from the vestibular nuclei via the medial longitudinal fasciculus (MLF) and interstitial nucleus of Cajal (INC) to a widespread cortical vestibular network [1]. SVV tilts are therefore observed across a range of vestibulopathies. Indeed, abnormal SVV has been reported in over 90% of patients with acute unilateral brainstem lesions affecting central pathways involved in gravitational perception [2]. SVV tilts are thought to arise as part of the ocular tilt reaction (OTR) characterized by the additional features of head tilt, ocular torsion, and skew deviation [3]. In support of this hypothesis, a tight correlation between torsional eye position and the SVV tilt has been described [4]. Unilateral brainstem lesions caudal to the pons lead to ipsiversive OTR and SVV tilts, whereas more rostral lesions involving the MLF or INC typically cause contraversive OTR and SVV tilt [2,5].

SVV is usually tested in a ''static'' condition, where subjects are asked to align a rod or line to Earth vertical against a black stationary background, devoid of reference frames. Recent studies demonstrate additional benefits of dynamic SVV test, whereby the rod or line is presented against a moving background (typically consisting of ''dots'' or ''spheres'') [6–8]. Dynamic conditions increase the sensitivity of the test, in addition to quantifying the degree of visual dependency – an over-reliance on vision for balance where other sensory modalities may be more appropriate [9]. Despite its clinical value in the diagnosis, topographical localization, and identification of impaired graviceptive (otolithic and vertical semicircular canal) function, the SVV has not entered mainstream clinical practice. This is mostly because SVV has been traditionally measured using specialist equipment involving the computerized ''hemispheric dome'' method, or a computerized ''light-bar in the dark'' method [8,10]. More recently, the ''bucket test'' was introduced as an inexpensive, easy-to-make, and easy to apply and operate method of testing the SVV at the bedside [11,12]. Although it has yielded reliable results, such a method is not without its limitations; namely a low resolution, and the ability to perform only static SVV tests [11,12]. Additional software-based, flexible multifunction systems have been proposed, but these systems are PC- or laptop-based and are less readily portable than hand-held devices [13].

In this study, we describe a virtual reality (VR) based system (VIRVEST) that has been developed to test SVV, and report normative values across healthy population. We sought to compare SVV results using VIRVEST system with previously reported in the literature using alternative methodologies. Additionally we wanted to choose controller which would be accurate and at the same time easy to use for the participants. Therefore, we selected 2 possible control devices and compared the differences between them. As it is known that virtual reality itself can cause dizziness, we wanted to evaluate possible virtually induced dizziness.

## 2. Materials and methods

### 2.1. VIRVEST system

VIRVEST is a wearable VR-based system that enables the physician or technician (herewith termed ''tester'') to acquire SVV data from a subject or patient (herewith termed ''participant''). The equipment is integrated by using the proposed software and hardware applications shown in Fig. 1. The participant wears a mobile virtual reality application (Mobile Application for Virtual Reality) in order to observe a 3D stimulus presented across four separate conditions. The virtual reality environment is controlled by the patient using a Bluetooth connected controller. In this study, we used the Samsung Galaxy S7 smartphone and Samsung Gear VR headset for virtual reality scene presentation. Participants controlled the movement of an ''arrow'' (Tests 1–3), or ''boat'' (Test 4) using either a Myo gesture control armband (Thalmic Labs Inc., Canada) or a general purpose gamepad (Red Samurai gamepad, GameStop Corp. Inc., US). The Myo armband (Fig. 1) was worn over the participant's forearm, and enabled the participant to rotate the arrow or boat wirelessly using pronation and supination arm motions. The Myo device consists of a set of electromyographic sensors, combined with a gyroscope, accelerometer and magnetometer to recognize arm gestures. The gamepad consisted of two buttons, left and right, which participants were asked to press to adjust the arrow or boat to their perceived vertical.

A second mobile device and software application (see mobile application in Fig. 1) was used to control the delivery of the VR stimulus. Additionally, this application allows the tester to visualize the test results both online and offline. The two mobile applications use Bluetooth connection in order to exchange the commands and data. The mobile application of the tester allows the data to be saved to a local database or to

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