Validation Study of Wireless Virtual Reality Head-Mounted Display for Sensory Integration in Balance Testing of Older Adults

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ABSTRACT

Falls represent a significant risk to older adults, so there is a need to readily assess balance abilities in to prevent future falls. A critical component of balance is sensory integration, but to objectively assess it requires expensive devices, such as the Neurocom Smart Equitest, that are often not accessible outside the clinic. The current study compares a novel VR head-mounted display sensory integration test to the Neurocom Smart Equitest to evaluate criterion-measure validity and determine the novel VR device's sensitivity to age-related balance differences. Current results suggest that the VR-based test provides a portable and affordable alternative for detecting age-related deficits in postural control.

1. INTRODUCTION

One out of every four adults over the age of 65 fall each year and fall-related injuries can be devastating to the overall well-being of older adults, leading to broken bones, head injuries, and psychological changes (Bergen, Stevens, & Burns, 2016; Florence et al., 2018). Therefore, it is important to objectively assess fall-risks in older adults to help reduce this risk. Sensory integration is crucial for maintaining stability and preventing falls. However, objective assessments for sensory deficits in the clinic can be costly. The gold-standard for computerized dynamic posturography is the Neurocom Smart Equitest's Sensory Organization Test (SOT), which has been shown to be sensitive for detecting the effects of aging on sensory integration for balance and fall-risk (Wallmann, 2001). However, this equipment can cost tens of thousands of dollars and is inaccessible beyond the clinic. With the recent advances in virtual reality, the current study examines the feasibility of assessing deficits in visual, vestibular and somatosensory processing for postural stability using a low-cost, portable VR head-mounted display (HMD) as compared to the SOT.

2. METHODS

Fourteen older adults (mean age = 70±4 yrs) and 16 healthy younger adults (mean 27±5 yrs) participated in the study. The participants first completed balance questionnaires and assessments that included: Activities Balance Confidence (ABC), Fall Efficacy Scale (FES), Timed up-and-Go (TUG), and Berg Balance Scale (BBS). Participants then performed the three trials of the six Neurocom SOT conditions and eight conditions of a custom-designed VR Sensory Integration in Balance (SIB) test (see Table 1). Participants wore an HMD (Lenovo Mirage, Hong Kong, China) that displayed a space station during VR SIB tests. Center of pressure from Neurocom and head displacement from HMD were used to calculate the *Equilibrium Score (ES)* to indicate postural stability (Vanicek, King, Gohil, Chetter, & Coughlin, 2013). The ES ranges from 0 to 100, where 0 represents a fall and 100 represents perfect stability. ANOVA, Binomial logistic regression, and ROC curve analysis were performed on the ES.

3. RESULTS

Paired T-Tests revealed significant differences between age groups in age ($p < 0.001$), ABC ($p<0.05$), FES ($p<0.05$), and BBS ($p<0.005$) scores, but not in TUG ($p=0.16$, n.s.). Repeated-measures ANOVA showed younger adults performed significantly better than the older adults on all conditions when tested with VR SIB ($F_{1,27}=22.2$, $p<0.001$) and with the NeuroCom SOT ($F_{1,27}=11.7$, $p=0.002$). Binomial logistic regression (Forward stepwise method) revealed that the VR SIB condition 8 (DYN-Foam) could discriminate age groups with 89.7% accuracy while the Neurocom SOT condition 6 (Sway-reference visual and surface) was 82.8% accurate.

Table 1. *Description of the six NeuroCOM SOT and the eight VR SIB conditions.*

Condition	NeuroCom SOT	VR SIB
1. EYES OPEN FIRM	Eyes open standing on firm surface.	Eyes open in VR standing on firm surface.
2. EYES CLOSED FIRM	Eyes closed standing on firm surface.	Eyes closed standing on firm surface.
3. EYES OPEN SWAY REFERENCE VISUAL	Eyes open standing on firm surface with sway reference wall (i.e., when user tilts forward, the walls also tilt forward).	Eyes open in sway referenced VR standing on firm surface. The point of view of VR scene moved with the user.
4. EYES OPEN SWAY REFERENCE SURFACE	Eyes open standing on a sway referenced surface (i.e., when the user tilts forward, the platform tilts forward).	Eyes open standing on a ~2.5-inch foam pad.
5. EYES CLOSED SWAY-REFERENCE SURFACE	Eyes closed standing on sway referenced surface	Eyes closed standing on a ~2.5-inch foam pad.
6. EYES OPEN SWAY-REFERENCE VISUAL + SURFACE	Eyes open standing on sway referenced surface with sway referenced wall surround.	Eyes open in sway referenced VR standing on a ~2.5-inch foam pad.
7. VISUAL DYNAMIC FIRM SURFACE (DYN FIRM)	n/a	Eyes open VR scene rotating clockwise or counterclockwise standing on firm surface
8.VISUAL DYNAMIC FOAM SURFACE (DYN-Foam)	n/a	Eyes open VR scene rotating clockwise or counterclockwise standing on a ~2.5-inch foam pad

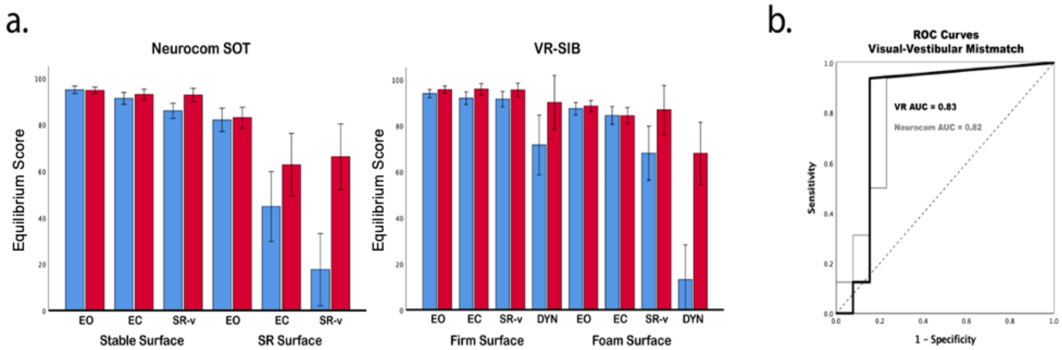

Figure 1. *SOT/SIB results across age cohorts. (a.) The sensitivity in detecting differences in balance performance between older (blue) and younger (red) adults were comparable on the Neurocom SOT and VR-SIB. (b.) ROC curves for novel VR device (thick black line) with AUC=0.83 and Neurocom (thin gray line) with AUC=0.82. EO = Eye Open; EC = Eyes Closed; SR-v = Sway Reference – Visual; DYN = Visual Dynamic.*

4. DISCUSSION and CONCLUSIONS

The current study reveals using VR to assess sensory integration in balance in healthy older adults versus healthy young adults was as sensitive at discriminating balance differences based on age-cohort as the Neurocom. Older adults had the greatest difficulty with test conditions involving visual-vestibular conflict, which challenged the postural control system to adjust its reliance on visual and somatosensory inputs (i.e. Neurocom SOT condition 6 and VR SIB condition 8). Further analysis of these conditions revealed challenging dynamic visual conditions with the VR device were higher than the Neurocom (89.7 vs. 82.8%) in discriminating between the two age-groups, and that AUC between devices were statistically equivalent. Functional assessments (TUG and BBS) on this same cohort of older and younger adults had notable weaknesses. TUG was not sensitive to age group comparison (p=0.16, n.s.) and BBS suffered from a ceiling effect in both cohorts. This is commonly seen in older adults on the BBS, which is limited in its ability to be challenging enough for community dwelling older adults or to predict fall-risk (Boulgarides, McGinty, Willett, & Barnes, 2003; Langley & Mackintosh, 2007). In conclusion, technology-based instrumented tests can be objective, repeatable, and valid tools to assess balance control. The current evidence suggests the novel VR SIB matches the gold-standard of Neurocom SOT and exceeds functional tests in detecting age-related deficits in balance control. However, the novel VR device has the advantage over other instrumented devices by being more cost-efficient and transportable, so it can be used in any location and even during a home-visit.

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