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Single Limb Support Instability combined with Vestibular and Proprioceptive Alteration in Hispanic Latinx Living with HIV

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ABSTRACT

Abstract: Healthy individuals can maintain static and dynamic balance via appropriate allocation among proprioceptive (Pro), vestibular (Ve), and visual sensory systems, established as the dynamic systems theory (DST). However, people living with the human immunodeficiency virus (PLHIV) underperform one or more of these systems, altering their ability to control balance. The issue is to determine specific balance system deficits in PLHIV during many challenging standing tasks to understand better where these deficiencies are located. The study aims to distinguish balance deficits in PLHIV using challenging activities with a reduced base of support.

Methods: Thirty adults living with HIV from La Perla Gran de Precio Community Center took part in this examination. We collected balance kinematics with accelerometers and gyroscopes during five balancing tasks. The five tasks included balancing on a firm surface with double limb support (DLS) and single limb support (SLS) and balancing tasks on an unstable surface (foam) with vertical head movements at 60 bpm set by a metronome.

Results: The balancing tasks requiring shifts from SL to DL on firm and foam surfaces with visual input alterations (eyes closed and open) and head movements showed significant increases in sway ($p<0.001$). The medial-lateral (ML) and anterior-posterior (AP) sway velocities displayed substantial increases ($p<0.001$) in AP sway among all five tasks and a considerable decrease in ML among the five tasks.

Conclusion: People living with HIV have balance instability, with increased difficulty during conditions requiring to bear weight on a single limb with Ve and Pro adaptations. The mechanism creating these deficits in the Ve and Pro systems is yet unsettled. Future studies should focus on 1) early assessment of Ve and Pro, 2) the mechanisms affecting said balance systems, and 3) the correlation of ART medications with balance and fall risk in this population.

Keywords: Standing Deviations, Motor control, Dynamic Balance, HIV complications, Single Limb Balance.

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INTRODUCTION

According to the Global HIV & AIDS statistics (UNAIDS), the human immunodeficiency virus (HIV) affects 38 million people worldwide, resulting in 690,000 deaths in 2019 [1]. From the initial exposure of HIV to the transformation of the virus into acquired immunodeficiency syndrome (AIDS), if left untreated, the immune system will weaken by the attack on white blood cells, especially CD4 cells, otherwise known as T cells. Invasion of the immune system by T cells does not directly disturb the nervous system; microglial cells or immune cells of the central nervous system (CNS) can be affected, leading to neurological deficits [2]. CNS involvement in those diagnosed with HIV can lead to neurological deficiencies, such as possible balance and gait impairments [3].

Balance is the ability to sustain the center of gravity (CoG) within the base of support (BoS). In humans, balance is controlled by integrating three sensory systems: somatosensory, vestibular, and visual [4]. The interplay of these networks is known as the dynamic systems theory (DST), showing that the collaboration of the three systems is integral to postural control, specifically with significant balance challenges such as modifying surface components from firm to soft [5-6]. When one system within the DST is impacted, sensory reweighting occurs to accommodate the lesser component to avert falls, emphasizing the remaining systems to control balance. The sensory reweighting can be observed and examined as postural adaptations; when the CoG travels beyond the BoS, these adaptations or balance mechanisms are known as hip, ankle, or stepping strategies required to avoid falls [5-6].

Individuals diagnosed with HIV can have neurological deficits that disturb the systems responsible for maintaining balance. Some of these neurological deficits provoking balance instability include vestibular involvement [7-8], lower leg neuromuscular system [9], and proprioceptive input [10]. Balance instability in those with HIV is displayed as a smaller functional BoS [11], considerably decreased limits of stability, and diminished stance stability [12] compared to healthy controls. One fundamental problem is that those living with HIV experience increased postural sway and decreased balance in the asymptomatic stage [13]. However, these balance modifications are not noticeable until substantial complications are evident, fall risk is unavoidable, and quality of life is impacted [14].

Accordingly, the ongoing inquiry intends to characterize balance deficits in PLHIV during multiple challenging single-leg standing tasks. Determining which sensory system is often disturbed in those living with HIV can assist in the formulation of tailored interventions that enhance balance and thus the quality of life.

METHODS

Participants

Participants were recruited by word of mouth from La Perla de Gran Precio, and HIV community center and clinic in San Juan, Puerto Rico. The inclusion criteria for this research were as follows: 1) a medical diagnosis of HIV. The exclusion criteria for this research were as follows: 1) significant stability problems, as shown by the inability to maintain double leg standing balance for less than 30 seconds; 2) trunk or lower extremity surgeries or traumas within the last six months; 3) medication of drugs that induce drowsiness 24 hours before participating in the study, and 4) pregnant women or those who could be pregnant.

Procedures

This research was approved by the IRB (protocol # 20092), and consent documentation was required and signed by all participants before testing and selecting processes. In addition, all demographic information and baseline vitals, including SaO^2 and heart rate, were collected at the initiation of data collection. The need for corrective lenses or contacts was also noted and documented during the screening process. Then, the participant completed the International HIV Dementia Scale (IHDS), five times sit-to-stand test (5xSTS), and the Fukuda stepping test (FST).

International HIV Dementia Scale (IHDS): The IHDS [15] includes a memory registration, motor speed, psychomotor speed, and a memory recall task. For the memory registration task, participants were asked to repeat the four words as directed by the tester, "dog, hat, bean, red." If the participant did not speak English or otherwise preferred Spanish, the four words were translated from the original scale to "perro, sombrero, habichuela, rojo." Motor speed was measured as the number of times the participant could bring their thumb and index finger together (as in a pincer grip) of their non-dominant hand and open again in five seconds. Psychomotor speed was measured as the number of times the participant could use their non-dominant hand to perform the following sequence of movements in 10 seconds: 1) first on a flat surface; 2) palm on a flat surface; 3) hand perpendicular to flat surface on the fifth digit. Memory recall was assessed by how accurately the participants could recall the four words from the memory registration task. Each task is scored 0-4, with zero being unable to achieve the task. The finished score is interpreted as the sum of all four tasks, with a final score equal to or less than 10 showing the need for further testing for possible dementia.

Fukuda stepping test: The FST [16] is a balance test related to the vestibular system used to assess labyrinthine function via vestibulospinal reflexes. To administer the FST, the participant stood on a grid with their upper extremities extended to 90 degrees and their eyes closed. After taking multiple steps in place, the displacement and rotation were measured. For this investigation, adhesive tape was placed on the floor to create a grid with 45°angles, rather than the traditional grid, which has concentric circles and is marked at 30°. We marked 45°rather than 30°because the cut-off score for the FST exceeds 45°of rotation. For the ages of our participants, 26.7-42.1 degrees of rotation could still be considered normal. While the Fukuda test is typically performed by taking 50 or 100 steps, participants were instructed to march for 30 s. After 30 s, the rotation and direction were recorded (ex. 45°on the left) [17].

Five Times Sit to Stand: 5xSTS was used to assess lower extremity functional mobility and strength. In this study, participants were directed to stand up and sit back down five times as swift as feasible, with their arms crossed over their chest. A free-standing bench was used for the assessment and was consistent for all participants. Time was recorded from when the tester said "go" to when the participant touched the chair on the fifth repetition [18].

Balance Protocol: Data was collected with the MobilityLab APDM MobilityLabTM (APDM Inc., http://apdm.com). MobilityLab is a gait and balance laboratory used for the examination of motion analysis and is transportable. The system uses accelerometer and gyroscope movements with lumbar sensors placed on the body to estimate spatial and temporal gait and balance parameters. Data were collected on medial-lateral (ML), and anterior-posterior (AP) sway velocity, direction, and distance.

During balance testing, one researcher stood behind the participant to guard against falls. If participants lost their balance, they could recover balance using their contralateral leg and continue with the trial. Researchers recorded the number of foot touchdowns by the contralateral limb for each test. Other movements to regain balance were not included in that count, including waving the extremities, leaning to one side, or hopping on the testing lower extremity.

All participants were given verbal instructions before each test. During the instruction time, the participants stood on a firm surface during rest breaks between trials. Each trial lasted 15 seconds and was preceded by a three-second countdown to the starting tone and concluded with an end tone. During each trial, participants balanced their dominant lower extremity 6 feet away from a blank white wall with two crossed pieces of black tape to focus their gaze at eye level. Each task lasted 15 seconds, started, and ended with the sound of a tone.

Task 1: At the starting tone, participants stood in a static standing balance with double limb support (DL) on a firm surface with eyes open. This task is referred to as the baseline task.

Task 2: Participants performed a single-leg balance on a firm surface with eyes open (SL firm). This task was designed to increase the challenge by reducing BoS.

Task 3: Participants started by standing on their dominant leg on a firm surface and performed cervical flexion and extension to move their heads up and down (HUD). Subjects were nodding yes to the beat of a metronome set to 60 bpm while maintaining their gaze on the black tape. At the starting tone, the participants closed their eyes (SL firm ECHUD). This task was constructed to cancel the visual input, challenge the vestibular system, and preserve the proprioceptive information unaltered.

Task 4: Participants adopted a single-leg balance position on a foam surface. Participants nodded the HUD to the metronome beat set to 60 bpm (SL foam EOHUD). This task was constructed to dispute the proprioceptive and vestibular systems simultaneously while leaving the visual information intact.

Task 5: Participants assumed a single-leg stance on a foam surface. At the starting tone, the participants were instructed to close their eyes (SL foam EC). This task was established to cancel the visual input and challenge the proprioceptive information while preserving the vestibular system.

Data Analysis

The Principal investigator placed the balance data into the SPSS Analysis 25 system for repeated measures ANOVA. During all five balance tasks, velocity and distance were gathered for each task's sway, AP, and ML Jerk. Due to the extensive analysis of the repeated measures ANOVA, this study considered a P-value of 0.01 or less significant.

RESULTS

This study included 30 participants, 19 males, and 11 females, with an average age of 60.31±7.82 years. The average number of years of diagnosis was 23.6 years. The average baseline vitals were as follows: resting heart rate (RHR) of 79 ± 15 beats per minute (bpm) and resting oxygen saturation (SaO^2) of 97.52 ± 1.02%. In addition, participants had averages for the following demographics: height of 65.59 ± 3.26 inches (in.), the weight of 177.17 ± 50.22 pounds (lbs), and body mass index (BMI) of 29.03 ± 8.10 kg/m². Of the above participants, five were left leg dominant, and 25 were right leg dominant. Twenty participants wore glasses or contact during the test administration, while 10 participants did not. Additional demographic information for all participants is shown in **Table 1**.

Table 1: Demographic data of all participants.

Characteristics	
Age (years)	M = 60.31±7.82
Gender	Male= 19 Female = 11
Year of Dx (years)	M= 1997 (23.6 years)
Cd4	M= 878.52
5-time sit to stand	13.34 seconds
Fukuda	L = 44.38 degrees R = 47.73 degrees
HIV dementia scale score	8.82
Resting heart rate (RHR)	79 ± 15 beats per minute (bpm)
Resting oxygen saturation (SaO_2)	97.52 ± 1.02%
Body mass index (BMI)	29.03 ± 8.10 kg/m².

The following variables were compared among the five balance tests mentioned in the methods section: sway, anterior-posterior jerk (jerk AP), medial-lateral jerk (jerk ML), the velocity of anterior-posterior sway (velocity AP), velocity of medial-lateral sway (velocity ML), the distance of anterior-posterior sway (distance AP sway), and distance of medial-lateral sway (distance of ML sway).

Table 2 illustrates the comparison of sway between the five different balance tests. The results showed that there was a significant increase in sway when comparing DL and SL firms on the surface (p<.001), DL and SLFirm ECHUD (p<.001), DL and SLFoam EOHUD (p<.001), and DL and SLFoam EC (p<.001). There was also a significant increase in sway when comparing SL firm surface and SL Firm ECHUD (p=.01), SL firm surface and SL Foam EOHUD (p<.001), and SL firm surface and SL Foam EC (p=.01).

Table 2: Comparison of sway between balance tests. Results of repeated measure ANOVA performed comparing tasks. Significance level set at p≤0.01

Sway	Means and SD	Means and SD	P-Value
	DL: 0.20 +/- 0.76	SLFirm: 3.07 +/- 3.46 SLFirm ECHUD: 6.31 +/- 4.65 SLFoam EOHUD: 8.50 +/- 6.14 SLFoam EC: 8.26 +/- 8.94	0.001* 0.001* 0.001* 0.001*
	SLFirm: 3.07 +/- 3.46	SLFirm ECHUD: 6.31 +/- 4.65 SLFoam EOHUD: 8.50 +/- 6.14 SLFoam EC: 8.26 +/- 8.94	0.01* 0.001* 0.01*
	SLFirm ECHUD: 6.31 +/- 4.65	SLFoam EOHUD: 8.50 +/- 6.14 SLFoam EC: 8.26 +/- 8.94	0.05 0.203
	SLFoam EOHUD: 8.50 +/- 6.14	SLFoam EC: 8.26 +/- 8.94	0.854
^DL= ^SL= ^EO= ^EC= ^HUD= ^P=P-Value ^S.D.=Standard Deviation ^P-Value>.01 is not significant *P-Value≤.01 is significant S.D.=Standard Deviation			

Table 3 shows the comparison between the different balance tests for jerk AP and jerk ML.

There was a significant increase in jerk AP when comparing DL and SL firms (p=.01) and DL and SL Foam EOHUD (p<.001). When comparing jerk in the medial and lateral directions, there was a significant increase in jerk between DL and SLFirm ECHUD (p<.001), DL and SLFoam EOHUD (p<.001), DL and SLFoam EC (p<.001), SLFirm, and SLFoam EOHUD (p<.001), and SL and SLFoam EC (p=.01).

Table 3: Comparison of jerk AP and ML between balance tests. Results of repeated measures ANOVA performed comparing tasks. Significance level set at p≤0.01

Jerk AP	Means and SD	Means and SD	P-Value
	DL: 21.33 +/- 98.21	SLFirm: 134.47 +/- 170.61 SLFirm ECHUD: 405.56 +/- 712.19 SLFoam EOHUD: 272.42 +/- 210.75 SLFoam EC: 348.01 +/- 642.34	0.01* 0.05 0.0018 0.05
	SLFirm: 134.47 +/- 170.61	SLFirm ECHUD: 405.56 +/- 712.19 SLFoam EOHUD: 272.42 +/- 210.75 SLFoam EC: 348.01 +/- 642.34	0.080 0.05 0.059
	SLFirm ECHUD: 405.56 +/- 712.19	SLFoam EOHUD: 272.42 +/- 210.75 SLFoam EC: 348.01 +/- 642.34	0.347 0.770
	SLFoam EOHUD: 272.42 +/- 210.75	SLFoam EC: 348.01 +/- 642.34	0.526
Jerk ML	Means and SD	Means and SD	P-Value
	DL: 19.56 +/- 90.70	SLFirm: 195.27 +/- 245.98 SLFirm ECHUD: 617.94 +/- 722.97 SLFoam EOHUD: 765.80 +/- 746.23 SLFoam EC: 422.97 +/- 342.30	0.05 0.001* 0.001* 0.001*
	SLFirm: 195.27 +/- 245.98	SLFirm ECHUD: 617.94 +/- 722.97 SLFoam EOHUD: 765.80 +/- 746.23 SLFoam EC: 422.97 +/- 342.30	0.05 0.001* 0.01*
	SLFirm ECHUD: 617.94 +/- 722.97	SLFoam EOHUD: 765.80 +/- 746.23 SLFoam EC: 422.97 +/- 342.30	0.071 0.118
	SLFoam EOHUD: 765.80 +/- 746.23	SLFoam EC: 422.97 +/- 342.30	0.05
^DL= ^SL= ^EO= ^EC= ^HUD= ^P=P-Value ^S.D.=Standard Deviation ^P-Value>.01 is not significant *P-Value≤.01 is significant S.D.=Standard Deviation			

A comparison of the velocity of anterior-posterior (AP) and medial-lateral (ML) sway between the five balance tests is shown in **Table 4**. There was a significant increase in the velocity of AP sway between DL and SL firms (p<.001), DL and SL firms ECHUD (p<.001), and DL and SL Foam EOHUD (p<.001). Further, there was a significant decrease in the velocity of medial-lateral (ML) sway between DL and SL firms (p<.001), but a significant increase in sway between DL and SLFirm ECHUD (p<.001), DL and SL foam EOHUD (p<.001), DL and SL foam EC (p<.001), SL and SLFoam EOHUD (p=.01), and SL and SL foam EC (p=.01).

Table 4: Comparison of the velocity of AP and ML sway between balance tests. Results of repeated measure ANOVA performed comparing tasks. Significance level set at p≤0.01

Vel AP	Means and SD	Means and SD	P-Value
	DL: 0.09 +/- 0.05	SLFirm: 0.42 +/- 0.37 SLFirm ECHUD: 0.52 +/- 0.34 SLFoam EOHUD: 0.45 +/- 0.23 SLFoam EC: 9.62 +/- 43.32	0.001* 0.001* 0.001* 0.303
	SLFirm: 0.42 +/- 0.37	SLFirm ECHUD: 0.52 +/- 0.34 SLFoam EOHUD: 0.45 +/- 0.23 SLFoam EC: 0.57 +/- 0.49	0.283 0.737 0.319
	SLFirm ECHUD: 0.52 +/- 0.34	SLFoam EOHUD: 0.45 +/- 0.23 SLFoam EC: 9.62 +/- 43.32	0.378 0.324
	SLFoam EOHUD: 0.45 +/- 0.23	SLFoam EC: 9.62 +/- 43.32	0.320
Vel ML	Means and SD	Means and SD	P-Value
	DL: 0.42 +/- 0.80	SLFirm: 0.30 +/- 0.25 SLFirm ECHUD: 0.48 +/- 0.37 SLFoam EOHUD: 0.57 +/- 0.38 SLFoam EC: 0.57 +/- 0.49	0.001* 0.001* 0.001* 0.001*
	SLFirm: 0.30 +/- 0.25	SLFirm ECHUD: 0.48 +/- 0.37 SLFoam EOHUD: 0.57 +/- 0.38 SLFoam EC: 0.57 +/- 0.49	0.05 0.01* 0.01*
	SLFirm ECHUD: 0.48 +/- 0.37	SLFoam EOHUD: 0.57 +/- 0.38 SLFoam EC: 0.57 +/- 0.49	0.272 0.272
	SLFoam EOHUD: 0.57 +/- 0.38	SLFoam EC: 0.57 +/- 0.49	0.958
^DL= ^SL= ^EO= ^EC= ^HUD= ^P=P-Value ^S.D.=Standard Deviation ^P-Value>.01 is not significant *P-Value≤.01 is significant S.D.=Standard Deviation			

Lastly, **Table 5** compares distance in AP sway and ML sway between the five balance tests. There was a significant increase in the length of AP sway between DL and SL firms (p<.001), DL and SL firms ECHUD (p<.001), DL and SL Foam EOHUD (p<.001), DL and SL Foam EC (p<.001), SL firm and SL firm ECHUD (p=.005), SL and SL Foam

EOHUD (p<.001), and SL and SL foam EC (p<.001). When comparing the ML sway, there was a significant increase in sway between DL and SL firms (p<.001), DL and SL firms ECHUD (p<.001), DL and SL foam EOHUD (p<.001), DL and SL foam EC (p<.001), SL firm and SLFirm ECHUD (p=.01), SL firm and SLFoam EOHUD (p<.001), SL and SLFoam EC (p<.001), and SLFirm ECHUD and SLFoam EOHUD (p=.01).

Table 5: Comparison of the distance of AP and ML sway between balance tests. Results of repeated measure ANOVA performed comparing tasks. Significance level set at p≤0.01

Dist AP	**Means and SD**	**Means and SD**	**P-Value**
	DL: 9.82 +/- 19.94	SLFirm: 47.23 +/-29.70 SLFirm ECHUD: 82.41+/- 57.94 SLFoam EOHUD: 81.06 +/- 36.91 SLFoam EC: 73.54 +/- 44.73	0.001* 0.001* 0.001* 0.001*
	SLFirm: 47.23 +/-29.70	SLFirm ECHUD: 82.41+/- 57.94 SLFoam EOHUD: 81.06 +/- 36.91 SLFoam EC: 73.54 +/- 44.73	0.005 0.001* 0.001*
	SLFirm ECHUD: 82.41+/- 57.94	SLFoam EOHUD: 81.06 +/- 36.91 SLFoam EC: 73.54 +/- 44.73	0.907 0.463
	SLFoam EOHUD: 81.06 +/- 36.91	SLFoam EC: 73.54 +/- 44.73	0.389
Dist ML	Means and SD	Means and SD	P-Value
	DL: 8.24 +/- 20.70	SLFirm: 63.48 +/- 49.87 SLFirm ECHUD: 106.84 +/- 60.52 SLFoam EOHUD: 135.75 +/- 73.60 SLFoam EC: 106.57 +/- 61.10	0.001 0.001* 0.001* 0.001*
	SLFirm: 63.48 +/- 49.87	SLFirm ECHUD: 106.84 +/- 60.52 SLFoam EOHUD: 135.75 +/- 73.60 SLFoam EC: 106.57 +/- 61.10	0.01* 0.001* 0.001*
	SLFirm ECHUD: 106.84 +/- 60.52	SLFoam EOHUD: 135.75 +/- 73.60 SLFoam EC: 106.57 +/- 61.10	0.01* 0.976
	SLFoam EOHUD: 135.75 +/- 73.60	SLFoam EC: 106.57 +/- 61.10	0.023

^DL=
^SL=
^EO=
^EC=
^HUD=
^P=P-Value
^S.D.=Standard Deviation
^P-Value>.01 is not significant
*P-Value≤.01 is significant
S.D.=Standard Deviation

DISCUSSION

This study intended to describe balance deficits in PLHIV through various balance tasks to understand which sensory system is most compromised. Based on our discoveries, PLHIV has balance difficulties when asked to perform tasks involving a single-limb stance. Additionally, PLHIV cannot enact proper postural control mechanisms when two balance systems are compromised, with the proprioceptive and vestibular systems altered the most.

Our first primary discovery was that PLHIV exhibited an enlarged postural sway in all variables of interest (jerk, velocity, and distance) when shifting their BoS from double legs on the ground to single-limb support. This result indicates that PLHIV are losing their capacity to stabilize on one leg due to balance sensory and neuromuscular activation deficits. This outcome aligns with the results of a related investigation by Rosario et al. [13], in which asymptomatic PLHIV in Puerto Rico had multi-directional postural instability. Since the Rosario et al. study [13] was executed on a similar convenience sample from the same HIV clinic as the present inquiry, this study's consistency further reinforces the uncovering that postural sway is increased in this population. In Brazil, Pimenta et al. described an increment in postural sway, notably with medial-lateral oscillations, when the BoS decreased from double limb support to a tandem stance [18]. Contrary to the Pimenta research, the current study did not compare dual limb support to tandem stance; nevertheless, double limb to single-limb support challenges balance by reducing BoS. Even with different methods of decreasing the BoS, Pimenta et al. [18] and the ongoing study noted a considerable increase in postural sway in PLHIV.

Based on this outcome alone, it is uncertain which components are responsible for most of the observed postural instability in this group. Nevertheless, the 5STS score is above the norm (13.3sec) for people from 60 to 69 years old, suggesting that lower limb weakness could increase postural sway [19]. The 5STS is designed to determine the functional capability and fall risk associated with lower limb strength [20]. A score above 12 seconds is related to a high risk of falls and a need for further fall risk assessment [21]. Participants in this study score 13.34 seconds, as revealed in table 1. The higher score for the 5STS suggests that lower limb weakness is related to the increased postural instability in an ML and AP direction. Vestibular involvement is another factor supporting the instability in these participants. Our outcomes revealed a deviation in the Fukuda score in most of the participants (table 1), showing vestibular issues towards the same side the rotation occurred [17]. Therefore, vestibular problems, prevalent in those living with HIV [7-8] are another reasonable factor provoking balance instability in this group.

Further, it could be speculated that decreasing the base of support from double limb to single-limb support generates postural instability by reducing somatosensory input, therefore challenging the vestibular and visual systems. Postural sway could also increase in this condition due to decreased neuromuscular control or other confounding variables, such as the use of ART. Previous examinations have yet to correlate increased postural sway with neuromuscular activation of the GA and TA based on EMG findings [13,10] Regardless, Rosario et al. found parallels in muscle amplitude [13]; however, variation in neuromuscular activation [22] in an HIV group compared to control individuals with postural instability during balance tasks. The Rosario et al. [13, 22] studies highlighted several alternative positions to the interpretation that balance instability might be related to various neuromuscular impairments associated with HIV. Future research could explore whether neuromuscular impairments from EMG findings and outcomes, such as Fukuda and 5TST, are correlated with increased falls.

Additionally, while ART has been associated with reduced bone mineral density (BMD), no examinations to date have attempted to associate ART with neuromuscular control or balance [23]. The literature could benefit from studies evaluating ART's effects or different cocktails on balance, falls, and neuromuscular control.

The second primary outcome revealed that when two sensory systems are challenged simultaneously (Visual (Vi)/Proprioception (Pro), Vestibular (Ve)/Pro, or Vi/Ve), the third system is incapable of sustaining adequate postural control. The above remark can be observed via significant increases in sway jerk, distance, and velocity in the AP and ML directions. Bestowing to the sensory reweighting theory, when two balance systems are challenged, the prevailing system must reallocate postural control to avoid excessive postural control movements. This process can only be successful when the third system is healthy and unchallenged [5-6]. When two of these systems become impaired, the ability to withstand postural control is markedly altered [24]. The outcomes mentioned demonstrate that this group of individuals displayed alterations in at least two of the three sensory systems, Vi, Pro, or Ve, with the inability to sustain proper balance in the absence of two of these systems.

Proprioception can be explained as recognizing one's body in space by receiving signals from mechanoreceptors and proprioceptors in tendons, muscles, ligaments, and joint capsules within the musculoskeletal system, showing the relationship between the extremities and the body to space [25]. These proprioceptive signals are pivotal in preserving the upright orientation of the body in static and dynamic activities. As stated by Henry and Baudry [26], alterations found in the muscle spindles and neural pathways of proprioception become hyposensitive, reduce in acuity, and cannot integrate into a proprioceptive signal in aged populations. Similar to our findings, this population relies on vestibular and visual systems to forestall increased postural sway associated with a greater incidence of falls and mortality in older individuals due to decreased accuracy of proprioceptive input [26]. Nevertheless, the vestibular system can become impaired in healthy aging adults, manifesting as difficulties with spatial orientation in the absence or unreliability of visual and surface information from the environment, resulting in increased fall risk [7]. Future directions should delve into whether individual balance control mechanisms can be untrained to proactively address the shortfalls seen in the elderly and PLHIV. For example, prospective studies should focus on training affected balance systems in PLHIV, predominantly asymptomatic individuals, to delay or deter more abrupt balance deficits through disease progression.

The third notable discovery of this inquiry revealed that when activities were executed on a foam surface (Pro) with head movements (Ve) or eyes closed conditions (Vi), postural instability was comparable. This result indicates the equivalent deficits seen in this group among the Pro and Ve systems. A potential justification for the proprioceptive deficits encountered in this investigation could be related to comorbidities. Comorbidities, such as neuropathy, can directly influence the proprioceptive system. As detailed above, proprioceptive impairments are prevalent in older adults, which is analogous to our findings of proprioceptive deficits in PLHIV [26]. Rosario et al. [3] conducted observational research of 1,300 files of PLHIV, including demographic characteristics (age, gender, ethnicity), comorbidities, medications, complete blood count workups, years of HIV diagnosis, and more. Among the data compiled in this study, one of the most prevalent comorbidities identified was neuropathy, hypertension, depression, and hyperlipidemia. The mechanism of neuropathy in PLHIV is due to inflammation secondary to the virus-damaging sensory and motor peripheral nerves in distal body segments. This destruction contributes to abnormal sensory distributions manifested as paresthesia, pain, and muscular weakness, as Rosario et al. [27] explained in their examination.

Another explanation for the results observed could be antiretroviral treatment (ART) medications, many of which are presently prescribed to curb the advancement of their disease. In the same observational study by Rosario et al. [13], an average of 2-3 different antiretroviral medications were taken by 63% of the 1,300 participant records analyzed. Like any medication, ART medications include many side effects such as dizziness, headache, depression, numbness, tingling, muscle pain, or burning sensations in the hands and feet (www.aidsinfo.nih.gov). Each of these side effects can potentially alter the proprioceptive and vestibular system's ability to sustain postural control. Hence, we speculate that some deficits revealed in our investigation are because of polypharmacy and the combination of ART medications and their side effects.

The mechanism of HIV in vestibular alterations in these individuals continues unclear, with further deficits identified with disease progression. Cohen et al. [28] explained that the relationship between HIV and vestibular dysfunction remains unsettled. Yet, the virus or medications disturb the vestibular system directly via central vestibular pathways or indirectly from opportunistic infections with secondary effects. Regardless, it is known that those living with HIV present vestibular issues [7-8]. Comparable to the explanation for these deficits, the ART medications of these people could generate postural instability. In addition, later stages of HIV disease progression have been associated with diminished nerve conduction velocity [29]. Thus, one notion that the current study is postulating is that the vestibular system is modified because of a deficit of the nerve conduction for the vestibulocochlear nerve, therefore affecting postural control mechanisms that contribute to balance instability.

This study considers several limitations. First, this investigation was entirely based on a convenience sample of Puerto Rican participants recruited from the same HIV rehabilitation clinic. Nevertheless, La Perla de Gran Precio's participants are from diverse territories of Puerto Rico, making this location an equitable depiction of Hispanic-Latinx in Puerto Rico. The second constraint of this inquiry refers to some of our participants having comorbidities or impairments that could have confounded our results. The enrollment of participants at various stages of HIV infection was intentional for favorable recognition of the balance profile of this population. However, we are aware of the influence of other comorbidities on balance. For instance, at least one participant had diabetes, which could also impair all three balance systems (somatosensory, vestibular, and visual) in the presence of diabetic peripheral neuropathy [30]. Further, some participants had considerable visual impairments despite the use of corrective lenses. Vision is one of three balance systems. Future investigations could identify balance profiles in those with HIV; however, separating the distinct groups among the different comorbidities to adequately recognize the implications of balance.

CONCLUSION

This research intended to investigate whether balance deficits could be successfully identified in PLHIV by challenging the specific balance systems in various standing positions. Our investigation found deficiencies in the ability of PLHIV to preserve balance with the appropriate resources from the vestibular, proprioceptive, and visual systems. Although the outcomes detected in our examination illustrate altered balance control mechanisms in PLHIV, the concurrently existing comorbidities affecting some participants' same balance control systems cannot be ignored as a constraint to this study.

In summary, our findings reveal that PLHIV has increased postural sway when their BoS is reduced from DL to SL support. Increased postural sway was detected in the AP and ML directions when two of the three sensory systems (Ve/Vi/Pro) were placed stressed with an inability of the remaining system to compensate for successful postural control. Under test conditions involving a foam surface with eyes closed and head movements, equivalent deficits were revealed in the Ve and Vi systems. The discoveries of this investigation can be employed as a guide for therapists to design further balance intervention plans for Hispanic-Latinx PLHIV or all PLHIV regardless of ethnicity.

Previous investigations into PLHIV have deduced deficits in the Ve systems without recognized mechanisms of alteration from HIV in the Ve system [28, 7-8]. The novel idea we suggest shows equivalent involvement of Ve and Pro in PLHIV even in asymptomatic stages of virus progression. Our notion is similar to the concept introduced by Rosario and colleagues, who identified multi-directional postural instabilities in asymptomatic PLHIV with further investigation into the individual systems comprising balance [13]. Similarly, Song et al. [31] surmised that when static postural control is impaired in elderly adults because of aging, there is an increased reliance on proprioceptive resources during dynamic balance control. The findings of this study strengthen our argument of the importance of early Pro and Ve balance management in PLHIV, regardless of symptom presentation, because of increased reliance on these two systems as Vi and Ve systems decline with disease progression and age [31].

We make recommendations based on our findings for healthcare professionals, specifically physiotherapists, working in patient populations living with HIV to assess and treat Ve and Pro systems regardless of subject presentation. This urge develops from our discoveries highlighting the deficits as alluded to above in asymptomatic and symptomatic PLHIV. Treating these postural control mechanisms before visible deterioration can be detected could be the key to aid in decreased fall risk and reduced mortality in this population [26].

Subsequent work should focus on identifying the origin of the deficits described in this study. Researchers should look into whether various combinations of ART medications, duration of HIV diagnosis, or gender relationships relate to deficits observed in the proprioceptive and vestibular systems connected to balance. This future effort could help single out the cause of deterioration and treat balance impairments adequately before falls emerge in PLHIV. Additionally, further investigation should delve into electromyography muscle activity of the lower extremity while balancing tasks, gait, and dual tasking conditions to better determine sources of balance systems' inadequacies to deal with these deficits.

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