ORIGINAL ARTICLE

IJPHY

Ankle Complex Neuromuscular Coordination Variation in People Living with HIV

[*1]Martín G. Rosario, PT, Ph.D., CSFI, ATRIC
[2]Abigail Schacherl, SPT
[3]Gayle Bevers, SPT
[4]Kendra Longoria, SPT
[5]Abigail Versemann, SPT

ABSTRACT

Background: People living with HIV (PLHIV) can exhibit impaired postural control because of infection or secondary medication effects, even with no history of falls. In PLHIV, balance deficits are associated with neuromuscular activation variations, muscle weakness, and complications with the vestibular and proprioceptive systems. We intend to determine neuromuscular activation coordination patterns of the tibialis anterior (TA) and gastrocnemius (GA) during eight different balance activities in physically active PLHIV.

Methods: 55 participants were recruited to participate in this non-randomized control trial, 24 of whom had been diagnosed with HIV. We collected the neuromuscular profile from both groups to assess TA and GA muscle activity during static balance tasks with and without cognitive dual tasking.

Results: Neuromuscular coordination patterns were dissimilar (p-value ≤ 0.05) in the HIV group in GA onset during eyes open on foam (EO FOAM), GA and TA duration and decay activity during eyes closed on foam (EC FOAM), and duration during eyes-closed head up and down (EC HUD). No considerable differences (p-value > 0.05) were observed with the addition of a cognitive task.

Conclusion: During the disease's controlled stages, HIV or its medications cause a miscommunication between the ankle complex musculature and the vestibular input related to postural control. These neuromuscular modifications are more noticeable in single tasks requiring higher recruitment of the vestibular input to sustain balance, such as an unstable surface with no visual information. Directions for subsequent investigation include gathering participants with various physical activity levels, medications, CD4 counts, lengths of time since diagnosis, and examining balance during more advanced tasks, such as dynamic balance activities and motor dual-tasking.

Clinical Relevance: Identify balance disturbances in PLHIV to reduce or prevent the risk of falls or injury. Specific deficits identified in PLHIV can be used to tailor interventions and address the balance systems at fault.

Keywords: HIV, balance response, dual-task, single-task, cognitive task, postural control, neuromuscular coordination.

Received 28th November 2020, accepted 27th February 2021, published 09th March 2021

www.ijphy.org

DOI: 10.15621/ijphy/2021/v8i1/907

[2]Texas Woman's University, Physical Therapy Program, Dallas Campus, Texas.
[3]Texas Woman's University, Physical Therapy Program, Dallas Campus, Texas.
[4,5]Texas Woman's University, Physical Therapy Program, Dallas Campus, Texas.

CORRESPONDING AUTHOR

[*1]Martín G. Rosario PT, Ph.D., CSFI, ATRIC

Texas Woman's University, Physical Therapy Program, Dallas Campus; 5500 Southwestern Medical Ave. Dallas, TX 75235-7299
Email: mrosario1@twu.edu

INTRODUCTION

HIV affects 36.9 million individuals worldwide, 1.1 million of which are in the United States (US), according to the Human Immunodeficiency Virus (HIV) Surveillance Report published by the Centers for Disease Control and Prevention [1]. The virus replicates within brain structures, producing motor-cognitive transformations, one of the distinct complications of HIV. These alterations interfere with everyday activities and are correlated to a lower quality of life, thereby increasing demand for caretakers and the healthcare system.

Antiretroviral therapy (ART) promotes the health and quality of life of those living with this illness. However, despite advancement with ART, HIV still detrimentally affects gait and balance, leading to a heightened risk for falls, trauma, and premature mortality [2, 3, 4]. In people living with HIV (PLHIV), ART promotes longer life expectancies, contributing to a greater risk of enduring negative repercussions associated with living longer with this disease [5, 6, 7, 8]. For instance, older men living with HIV had a greater endangerment of developing slow gait speed, as Schrack et al. in 2015 [9] indicated in their review. Gait speed is prognostic of advanced aging among this population, including a faster functional decay rate. Researchers outlined the consequence of the association between age and HIV status, showing that the longer people live with HIV, the more impactful this disorder is on the neurocognitive and neuromotor level [9].

We chose two primary mechanisms to feature in the current research responsible for the detrimental effects of gait and stability in PLHIV: neuromotor and neurocognitive factors. Neuromotor alterations induced by HIV are related to the assumption that ART damages mitochondria, impairs muscle function, and contributes to sarcopenia and osteoporosis. Sarcopenia and osteoporosis are associated with PLHIV and might affect their neuromotor function. Both elements could be partly responsible for the gait and balance deficits encountered in this population because of their effects on body strength and balance strategies. Decreased lower extremity strength emerges in compensation of increased coactivation of the tibialis anterior (TA) and soleus muscles, leading to increased use of the hip strategy and postural sway [10].

Inadequate selection of compensatory postural correction strategies is another crucial factor responsible for balance and gait impairments. Berner et al. in 2017 [10] found deficits in activities performed with eyes closed, showing the brain did not respond appropriately to the accurate proprioceptive and vestibular systems during these activities. These findings suggest the problem is undoubtedly a CNS issue, and the disease impacts the vestibular system, leading to increased frequency of movement and postural sway [10].

On the other hand, neurocognitive alterations such as depression [11], dementia, and anxiety affecting PLHIV [12] magnify cognitive deterioration and reduce life quality in this group. Neurocognitive alterations also increase fall risk and fear of falling in this population [13, 14].

Recent studies [15] have discovered alterations in lower extremity neuromuscular activation during balance activities requiring a cognitive component in PLHIV when matched to an HIV negative group. The lower limb modification was related to ankle complex musculature (TA and gastrocnemius (GA)) and challenging tasks requiring the recruitment of vestibular and proprioceptive control (standing on a foam mat while moving the head up-down). The authors pointed out a miscommunication between balance systems and neuromuscular characteristics as the plausible explanation for the balance alterations presented in the HIV group.

Although previous research has investigated the motor or cognitive implications on gait and balance, a question remains: can we identify specific early manifestations of the ankle complex musculature compensatory mechanism in PLHIV? Therefore, this inquiry seeks to determine neuromuscular changes in the TA and GA because of HIV influencing balance during dual-cognitive tasks. Various researchers described the cognitive or motor aftermaths of HIV affecting balance independently. Notably, the ongoing study proposes to scrutinize the compensatory mechanisms associated with a cognitive dual-task combined with different balance tests simulating real-life scenarios on GA and TA coordination on PLHIV.

METHODOLOGY

Participants

This investigation was approved (#20092) and adopted all privacy established by the Texas Woman's University (TWU) IRB in Dallas, Texas, and La Perla de Gran Precio (LPDG) in San Juan, Puerto Rico. All participants signed the informed consent and agreed to be part of this research.

The selected participants for both groups needed to have an age range between 25-80 years, the ability to walk without assistive equipment, and the capacity to endure the standing position for at least 30 minutes. The additional inclusion criteria for the HIV group involved the diagnosis of HIV by a medical doctor and CD4 levels above 200 cells/uL, which represented a stable immune system.

The present inquiry recruited 31 HIV-negative participants (7 male and 24 female) enrolled in the control group (CoG) (average age of 25.1±3.5 years, average BMI of 24.0-Table 1). Additionally, we enlisted the HIV group 24 (13 male and 11 female) participants of Hispanic-Latino origin diagnosed with HIV (average age 59.2 ± 1.7 years, with an average CD4 count of 612.3.

***Table 1**: Demographic data of all participants*

Characteristics	Control Participants n=31	HIV Participants n=24
Age	25.07 +/- 3.4 years	M=59.2 +/- 1.7 years
Gender	Male= 7 Female = 24	Male= 13 Female= 11
CD4		M= 612.25
BMI	M= 23.9	M= 25.1 +/- 5.7

Measures

Neuromuscular data was gathered via electromyography surface electrode system (EMG) (Delsys, Inc. Boston, MA) on the TA and GA. Within each task, we selected four data points for both muscles: time at the beginning of muscle activity (or onset), time at peak activity, muscle activation duration, and time at decay.

Procedures

After gathering the informed consent, vitals such as blood pressure and heart rate were collected for all participants. Subsequently, researchers identified the dominant leg by asking each participant which foot they would use to kick a ball. If needed, areas of the chosen leg were shaved with a non-electric razor to attach and secure the EMG electrodes' placement. An EMG surface electrode was situated over the TA and GA. All participants wore the EMG surface electrodes for the entire testing.

Balance Assessment

After fitting participants with the EMG sensors, each participant remained in a static bi-pedal posture on a firm surface for a baseline measurement. Following the baseline measures, a thick foam pad (thickness = 2.4 inches, length = 15.5 inches, width = 12.5 inches) was placed on a firm surface for the additional eight balance tasks. Participants resumed the same static bi-pedal posture on top of the foam pad. The foam component was designed to mimic unstable surfaces such as grass, gravel, or carpet and challenge the somatosensory system. Each task was recorded for 15 seconds. Balance tasks were segregated into four non-cognitive and four cognitive tasks. For each task, including the baseline measurement, we instructed participants to fixate their gaze on an orange square on the wall six feet above the floor and ten feet away from their position.

Four non-cognitive tasks were executed on the foam pad: 1) Eyes open (EO FOAM); 2) Eyes closed (EC FOAM); 3) Eyes open while moving the head up and down to the cadence of a 60 bpm metronome (EO HUD). Moving the head will provoke a firing of the vestibular system necessary to challenge said system (EO HUD); 4) Eyes closed while moving the head up and down to the rhythm of a 60 bpm metronome (EC HUD). Closing eyes or canceling the visual input, as we did in the EC FOAM and EC HUD tasks, provokes a balance disturbance of the vestibular and the somatosensory systems, similar to walking in a dark room. The purpose of the EO HUD task was to recreate scenarios where moving the head and fixing the gaze on a static object is required, for instance, reading a sign while walking.

The participants then completed four additional tasks while standing on a thick foam pad located on a firm surface. The cognitive dual-task component to the balance assessment was added by having participants count backward from 100 by threes while performing the same four tasks described above.

Data Analysis

In the ongoing examination, we performed secondary analyses of existing data to compare TA and GA neuromuscular timing coordination within each group. EMG's highest peak muscle activity for TA and GA was tracked down for each task between 0-15 seconds. At initiation, the position at peak activity, muscle activation duration, and decay time was marked for each task and both muscles. These numbers were tallied in a spreadsheet and imported into SPSS version 25 as the statistical program for further analysis. An ANOVA analysis was performed to compare TA and GA variables within groups for all balance tasks. A p-value of 0.05 or less was determined as significant in this study.

RESULTS

Data analysis revealed three significant findings from this research. For the first result, the HIV group exhibited an earlier onset of GA activity during EO FOAM than the control group, with a p-value of 0.05 (Table 3). In contrast, the control group showed no notable difference between the onset of TA and GA activity. Interestingly, during EC FOAM, only the control group showed a p-value of 0.05, indicating a significant difference in activation patterns (Table 2). Secondly, in both the HIV and control group, the GA demonstrated a variation in activity compared to the TA during EC HUD. Time to decay between TA and GA was prolonged in both groups, with the control showing a p-value of 0.005 and the HIV presenting a p-value of 0.05. Therefore, the difference in duration between TA and GA activity was only statistically significant in the control group, as indicated by a p-value of 0.05 (Tables 2 and 3). Thirdly, cognitive task addition did not demonstrate any significant difference in activation patterns between the TA and GA for either the HIV or control group (Tables 2 and 3).

Table 2: *Control Electromyographic (EMG), time to peak, duration, and decay of gastrocnemius during balance tasks in seconds. Results of analysis of variance ANOVA performed between asymptomatic HIV group and control group. Significance level set at p≤0.05.*

Task	Variables	TA (N =)	GA (N =)	P-value
EO Foam	Onset (sec)	8.08±3.96	7.78±5.57	.78
	Time to Peak (sec)	.54±.68	.49±.44	.72
	Duration (sec)	1.13±1.0	1.04±.74	.67
	Decay (sec)	.58±.44	.55±.45	.70
EC Foam	Onset (sec)	8.64±5.24	8.31±4.52	.77
	Time to Peak (sec)	.44±.29	.69±.53	.05
	Duration (sec)	1.03±.47	1.30±.75	.06
	Decay (sec)	.59±.33	.61±.37	.75
EO HUD	Onset (sec)	8.32±4.28	7.2±4.57	.27
	Time to Peak (sec)	.48±.28	.51±.40	.72
	Duration (sec)	.95±.43	1.12±.66	.19
	Decay (sec)	.47±.29	.61±.39	.74

EC HUD	Onset (sec)	8.02±5.78	6.94±4.86	.37
	Time to Peak (sec)	.47±.26	.51±.31	.45
	Duration (sec)	.95±.35	1.23±.60	0.05
	Decay (sec)	.49±.22	.72±.43	0.005
EO COG	Onset (sec)	9.6±4.44	9.68±5.26	.94
	Time to Peak (sec)	.48±.59	.54±.41	.61
	Duration (sec)	1.06±1.11	1.07±.67	.93
	Decay (sec)	.58±.58	.53±.42	72
EC COG	Onset (sec)	8.72±5.14	7.33±4.27	.19
	Time to Peak (sec)	.46±.24	.51±.53	.59
	Duration (sec)	.98± .48	1.14±.94	.33
	Decay (sec)	.52± .35	.63±.59	.31
EO HUD COG	Onset (sec)	9.56±4.74	8.92±5.61	.59
	Time to Peak (sec)	.58±.31	.57±.56	.91
	Duration (sec)	1.2±.68	1.32±1.22	.61
	Decay (sec)	.62±.54	.75±.88	.45
EC HUD COG	Onset (sec)	8.25±5.6	8.49±5.64	.85
	Time to Peak (sec)	.45± .29	.72±1.08	.14
	Duration (sec)	1± .45	1.2±1.17	.33
	Decay (sec)	.56±.33	.52±.41	.64

EO= Eyes Open, EC=Eyes Closed, HUD= Head up and down

***Table 3: HIV** Electromyographic (EMG), time to peak, duration, and decay of gastrocnemius during balance tasks in seconds. Results of analysis of variance (ANOVA) performed between asymptomatic HIV group and control group. Significance level set at p≤0.05.*

Task	Variables	TA (N =19)	GA (N =19)	P-value
EO Foam	Onset (sec)	7.94±4.82	11.35±5.53	.05
	Time to Peak (sec)	.43±.33	.57±.32	.20
	Duration (sec)	1.02±.64	1.28±.73	.25
	Decay (sec)	.59±.43	.71±.53	.43
EC Foam	Onset (sec)	8.07±4.62	10.48±5.48	.15
	Time to Peak (sec)	.78±.52	.68±.41	.55
	Duration (sec)	1.59±.10	1.60±.90	.97
	Decay (sec)	.81±.66	.91±.73	.55
EO HUD	Onset (sec)	10.01±6.44	10.31±5.72	.88
	Time to Peak (sec)	.44±.35	.67±.58	.15
	Duration (sec)	.98±.77	1.16±.68	.47
	Decay (sec)	.54±.52	.49±.27	.68
EC HUD	Onset (sec)	11.82±5.13	11.64±5.29	.92
	Time to Peak (sec)	.63±.40	.71±.64	.67
	Duration (sec)	1.18±.53	1.50±.75	.14
	Decay (sec)	.55±.32	.79±.32	.05
EO COG	Onset (sec)	12.10±5.21	13.17±6.11	.57
	Time to Peak (sec)	.59±.54	.44±.20	.26
	Duration (sec)	1.07±.75	.98±.42	.65
	Decay (sec)	.47±.39	.54±.34	.60
EC COG	Onset (sec)	8.23±4.84	9.27±6.13	.56
	Time to Peak (sec)	.43±.29	.52±.45	.46
	Duration (sec)	.86± .41	1.1±.63	.18
	Decay (sec)	.43± .27	.58±.40	.20
EO HUD COG	Onset (sec)	8.91±4.72	8.10±5.10	.29
	Time to Peak (sec)	.65±.47	.51±.34	.96
	Duration (sec)	1.22±.77	1.08±.59	.66
	Decay (sec)	.57±.40	.57±.31	.91
EC HUD COG	Onset (sec)	8.46±7.23	9.48±6.56	.65
	Time to Peak (sec)	.55± .37	.53±.33	.90
	Duration (sec)	1.13± .52	1.13±.67	1.0
	Decay (sec)	.58±.42	.59±.45	92

EO= Eyes Open, EC=Eyes Closed, HUD= Head up and down, COG = cognitive task counting backwards from 100

DISCUSSION

This study examined the TA and GA's coordination during single and cognitive dual-tasks to determine distinct neuromuscular patterns in participants with HIV. Previous evidence proved that ART had reduced some of the disease's difficulties, such as morbidity and mortality rates among PLHIV. This reduction of HIV progression increases lifespan and improves this population's quality of life [3].

We recognize that the participants in this study were proactive with their ART routines. Nevertheless, we based our study on the assumption that balance disturbances can be identified as illustrated in previous evidence even when the disease is stable. HIV can provoke mild to severe impairment of motor-cognitive abilities [16, 8]. Among these impairments, HIV is detrimental to normal cognitive function, gait, and balance stability, enhancing the risk for falls, injury, and premature death in these individuals [2, 3, 4].

Therefore, this study attempted to answer whether or not it was possible to identify early compensatory mechanisms in ankle complex musculature in PLHIV when the disease is stable. Our results revealed three noteworthy distinctions in the neuromuscular coordination patterns in the HIV group.

Our first finding reveals a lack of GA recruitment in the HIV group. The control group relied on GA compensation due to anterior sway direction during EC FOAM and EC HUD. Results showed that the control group exhibited a delayed time to peak difference with EC FOAM, where there was no distinction in the HIV group. The control group presented with adjustments in both GA duration and decay, indicating typical compensations for the EC HUD balance task. The HIV group displayed a variation in GA decay, revealing their loss of proper GA duration compensation. Similar to Rosario et al.'s 2020 [15] study, researchers identified different muscle activation patterns between TA and GA, pointing out the GA's alteration as an initial detrimental sign exhibited on the muscle with greater cross-sectional diameters. Further, the authors

attributed the deficit of neuromuscular issues to inadequate communication between the systems associated with balance and neuromuscular activation of said muscles.

Muscle weakness could be another explanation for the mismatched coordination patterns. Although the HIV group was enrolled in a community fitness center, the present work did not record the group's amount or type of exercise, making this a constraint of the study. Future inquiries should delve into the TA and GA's muscle amplitude to determine muscle strength and its role in balance.

Our second outcome showed the HIV group only presented a difference in GA decay, showing their lack of appropriate GA duration compensation. Contrary, the control group demonstrated differences in both GA duration and decay, implying average compensations for the EC HUD balance task. With the foam providing inaccurate proprioceptive information in all conditions and the visual system being canceled during EC FOAM and EC HUD, the participants relied mainly on the vestibular system to maintain balance.

The cancellation of the visual input and the proprioceptive alteration should re-weight the responsibilities of preserving balance to the unchallenged system, in this case, the vestibular system [17]. In 2016, Dakin et al. proposed that vestibular signals have a more substantial influence on motor units' activity than proprioceptive signals in healthy individuals [18]. The previous remark implies that any deficit in the vestibular system will have a considerable impact on balance, which we observed in PLHIV. The discoveries from our investigation indicate abnormal compensations in the HIV group may be because of a vestibular deficit. Similar to our findings, Berner et al. [10] mentioned HIV directly impacts the vestibular system, leading to increased frequency of movement and increased postural sway. Although the participants in our study were active with no history of falls within the last six months, Rosario et al. [19] revealed that balance deficits could be seen in PLHIV even when asymptomatic during challenging conditions, similar to the current study. Since we know vestibular deficits amongst PLHIV affect their balance, future studies should tailor a balanced program to provoke the balance systems' re-weighting towards the vestibular component. For instance, we are walking on a foam balance beam in a dark room.

In our third discovery, neither group displayed a variation in any of the dual tasks. These neuromuscular similarities may expose the cognitive dual-task during static balance was not sufficiently demanding to identify the balance deficits caused by the virus. The participants in this investigation were diagnosed with HIV rather than AIDS, the controlled stage of the illness, meaning the CD4 counts displayed in Table 2 are somewhat normal. Various studies reported that a normal CD4 count could slow down the advancement of impending complications such as dementia in this population [20]. Therefore, our research reveals that coordination pattern variations could be identified in PLHIV, even without alterations during cognitive dual-tasking.

The previous statement suggests the alterations in coordination identified in this study could demonstrate the balance deficit is localized more distally (lower extremities musculature) than proximally (CNS control of lower extremities). Multiple studies explain the impact of the virus replicating within the brain's immune cells, leading to inflammation in the brain's motor-cognitive areas and resulting in progressive cognitive and behavioral transformations [21, 22, 23, 24]. Considering the research and results discussed above, future considerations should incorporate participants with a more advanced HIV status and add cognitive dual-tasks during dynamic balance activities to ensure the participant is adequately challenged, as suggested previously by Berner et al. [10]. Researchers found balance deficits in the HIV population were more noticeable during more complex tasks. This position above suggests the task must be sufficiently challenging and match the participant's ability to distinguish between HIV and control participants.

CONCLUSION

This study distinguished neuromuscular activation patterns of the TA and GA during balance in physically active PLHIV. Our study expands on highlighting the alterations of vestibular inputs on the coordination of ankle musculature seen in PLHIV during the various balance tasks.

In the ongoing study, we came across some shortfalls. First, assessing only the TA and GA muscles restricts our ability to determine balance techniques in proximal areas such as the hip and trunk. We suggest testing the neuromuscular adaptation of the hip and back musculature, such as gluteus muscles and erector spinae, for a complete understanding of the impact of HIV on the motor system.

Second, describing early balance deficits in asymptomatic PLHIV is a noteworthy discovery of this study. However, we can only speculate the path this postural impairment will take in more advanced stages of the condition, making this finding a constraint in our examination. Future analysis should include recruiting participants with various physical activity levels, lengths of time on ART, CD4 counts, and time since diagnosis. Knowing these components could facilitate a more robust interpretation of balance deficits observed in PLHIV. These variables could advance our understanding of balance deficits along with the progression of HIV.

Finally, this inquiry only tested static balance during cognitive dual-tasking, leaving the dynamic component phase of postural control unattended. We suggest analyzing balance during more advanced tasks, such as dynamic balance activities, gait, ramp surface, or stairs combined with motor dual-tasking. These movements closely simulate daily living activities and will be more demanding than the static balance and cognitive tasks executed in this study. It is a possibility that the brain could compensate appropriately during the combined cognitive tasks since cognition and motor tasks use different parts of the brain,

as opposed to increasing demand on the same area of the brain. Additionally, walking and talking is an everyday task more complicated than standing and counting backward. Therefore, motor dual-tasking could enhance the participants' movements' complexity to sustain balance, potentially exposing more deficits.

Our study advances the notion that HIV motor impairments can be identified in active asymptomatic PLHIV. Recognizing the role of ankle musculature (GA and TA) and the early signs of vestibular alterations allow us to generate targeted intervention strategies intended to slow down the motor deterioration that ultimately influences this population's quality of life. We recommend health care providers focus on the treatment and rehabilitation of PLHIV using vestibular and lower limb musculature assessment-intervention in their protocols.

REFERENCES

[1] Centers for Disease Control and Prevention. Estimated HIV incidence and prevalence in the United States, 2010–2016. *HIV Surveillance Supplemental Report. 2019*; *24*(1).

[2] Cohen, H. S., Cox, C., Springer, G., Hoffman, H. J., Young, M. A., Margolick, J. B., & Plankey, M. W. Prevalence of abnormalities in vestibular function and balance among HIV-seropositive and HIV-seronegative women and men. *PloS one*. 2021; *7*(5): e38419.

[3] Erlandson, K. M., Allshouse, A. A., Jankowski, C. M., Duong, S., Mawhinney, S., Kohrt, W. M., & Campbell, T. B. (2012). Comparison of functional status instruments in HIV-infected adults on effective antiretroviral therapy. *HIV clinical trials*. 2012; *13*(6): 324–334.

[4] Heinze, B., Swanepoel, D. W., & Hofmeyr, L. M. Systematic review of vestibular disorders related to human immunodeficiency virus and acquired immunodeficiency syndrome. *The Journal of Laryngology & Otology*. 2011; *125*(9): 881-890.

[5] Cross, S., Onen, N., Gase, A., Overton, E. T., & Ances, B. M. Identifying risk factors for HIV-associated neurocognitive disorders using the international HIV dementia scale. *Journal of Neuroimmune Pharmacology. 2013; 8*(5):1114–1122.

[6] Havlik, R.J., Brennan, M., & Karpiak, S. E. Comorbidities and depression in older adults with HIV. *Sex Health*. 2011; *8*(4): 551–559.

[7] Watkins, C.C., & Treisman GJ. Cognitive impairment in patients with AIDS - prevalence and severity. *HIV AIDS. 2015; 7*(35).

[8] Woods, S. P., Moore, D. J., Weber, E., & Grant, I. Cognitive neuropsychology of HIV-associated neurocognitive disorders. *Neuropsychology review*. 2009; *19*(2), 152-168.

[9] Schrack, J. A., Althoff, K. N., Jacobson, L. P., Erlandson, K. M., Jamieson, B. D., Koletar, S. L., Phair, J., Ferrucci, L., Brown, T. T., Margolick, J. B. Accelerated longitudinal gait speed decline in HIV-infected older men. *Journal of acquired immune deficiency syndromes*. 2015; *70*(4): 370–376.

[10] Berner, K., Morris, L., Baumeister, J., & Louw, Q. Objective impairments of gait and balance in adults living with HIV-1 infection: a systematic review and meta-analysis of observational studies. *BMC musculoskeletal disorders*. 2017; *18*(1): 325.

[11] Rosario, M. G., Jamison, L., & Gines, G. The role of HIV Antiretroviral Medication on motor-cognitive and neurological alterations in Hispanic people living with HIV. *Journal of Public Health Issues and Practices. 2020; 4*(1).

[12] Banks, L. M., Zuurmond, M., Ferrand, R., & Kuper, H. The relationship between HIV and prevalence of disabilities in sub-Saharan Africa: systematic review. *Tropical medicine & international health*. 2015; *20*(4), 411–429.

[13] Shah, K. N., Majeed, Z., Yoruk, Y. B., Yang, H., Hilton, T. N., McMahon, J. M., Hall, W. J., Walck, D., Luque, A. E., & Ryan, R. M. Enhancing physical function in HIV-infected older adults: A randomized controlled clinical trial. *Health Psychology. 2016;35*(6): 563–573.

[14] Veeravelli, S., Najafi, B., Marin, I., Blumenkron, F., Smith, S., & Klotz, S. A. Exergaming in older people living with HIV improves balance, mobility and ameliorates some aspects of frailty. *Journal of Visualized Experiments. 2016;116.*

[15] Rosario, M. G., Marshall, J., Herkert, A., Binoy, B., Windham, H., & Orozco, E. Lower Limb Neuromuscular Modification and Standing Postural Control Alteration in Apparent Asymptomatic People Living with HIV. *Journal Rehabilitation Practices and Research. 2020; 1*(1),102.

[16] Cysique, L. A. & Brew, B. J. Neuropsychological functioning and antiretroviral treatment in HIV/AIDS: a review. *Neuropsychological Review. 2009; 19*(2): 169-85.

[17] Shumway-Cook, A., & Woollacott, M. H. *Motor control: Translating research into clinical practice. 2012;* (6th ed.). Philadelphia, PA: Wolters Kluwer Health, Lippincott Williams & Wilkins.

[18] Dakin, C. J., Héroux, M. E., Luu, B. L., Inglis, J. T., & Blouin, J. S. Vestibular contribution to balance control in the medial gastrocnemius and soleus. *Journal of neurophysiology*. 2016; *115*(3):1289–1297.

[19] Rosario, M. Early signs of standing postural instability in asymptomatic people living with HIV. HIV & AIDS Review. *International Journal of HIV-Related Problems. 2020; 19*(3), 193-198.

[20] Vajpayee, M., Kaushik, S., Sreenivas, V., Wig, N., & Seth, P. CDC staging based on absolute CD4 count and CD4 percentage in an HIV-1-infected Indian population: treatment implications. *Clinical and Experimental Immunology. 2005; 141*: 485-490.

[21] Chang, L., Tomasi, D., Yakupov, R., Lozar, C., Arnold, S., Caparelli, E., & Ernst, T. Adaptation of the attention network in human immunodeficiency virus brain injury. *Annals of Neurology: Official Journal of the American Neurological Association and the Child*

Neurology Society. 2004; *56*(2): 259-272.

[22] Paul, R. H., Yiannoutsos, C. T., Miller, E. N., Chang, L., Marra, C. M., Schifitto, G., Ernst, T., Singer, E., Richards, T., Jarvik, G. J., Price, R., Meyerhoff, D. J., Kolson, D., Ellis, R. J., Gonzalez, G., Lenkinski, R. E., Cohen, R. A., & Navia, B. A. (2007). Proton MRS and neuropsychological correlates in AIDS dementia complex: Evidence of subcortical specificity. *Journal of Neuropsychiatry and Clinical Neuroscience. 2007; 19*(3): 283–292.

[23] Sclar. G., Kennedy, C.A., Hill, JM, & McCormack, M. K. Cerebellar degeneration associated with HIV infection. *Neurology. 2000; 54*(4): 1012–1013.

[24] Von Giesen, H.J., Wittsack, H. J., Wenserski, F., Koller, H., Hefter, H., & Arendt, G. (2001). Basal ganglia metabolite abnormalities in minor motor disorders associated with human immunodeficiency virus type 1. *Archives of Neurology. 2001; 58*: 1281–1286.