NEUROSCIENCE RESEARCH NOTES

OPEN ACCESS | RESEARCH NOTES ISSN: 2576-828X

Electroencephalographic findings of young adult males during prolonged unipedal orthostasis

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Received: 12 August 2023; **Accepted:** 8 March 2023; **Published:** 26 April 2023
Edited by: Kamalanathan Palaniandy (Universiti Kebangsaan Malaysia, Malaysia)
Reviewed by: Raghuveer Raghumahanti (Gandhi Institute of Technology and Management, India); Lee-Fan Tan (Universiti Tunku Abdul Rahman, Malaysia); Kheng Seang Lim (Universiti Malaya, Malaysia)
https://doi.org/10.31117/neuroscirn.v6i2.177

Abstract: Previous investigations have enumerated the effect of prolonged bipedal orthostasis on body functions. The study investigated the effect of prolonged unipedal orthostasis on electroencephalographical tracings in young adult males. Twenty apparently healthy adult males aged 19-23 years were recruited for the study. Cardiovascular parameters and anthropometric indices were measured prior to the experiment. Exertional distress and orthostatic tolerance time were evaluated using Borg scale (6-20) and stop watch respectively as previously reported. Orthostatic tolerance time was defined as the time interval between assumption of unipedal position and the first perception of distress. Statistical test was done using SPSS 23 and significant difference was accepted at P<0.05. Prolonged unipedal orthostasis was characterised by significant increases in rate of perceived exertion and orthostatic tolerance time when compared with baseline values. During prolonged unipedal orthostasis, the frequency and amplitude of beta wave decreased, while alpha wave frequency and amplitude increased and decreased respectively when compared with the baseline. When compared with left leg orthostasis, there was an increase in alpha wave frequency during right leg orthostasis. Furthermore, stronger correlation coefficients were found between EEG fatigue index and rate of perceived exertion, orthostatic tolerance time, systolic blood pressure and diastolic blood pressure during right leg orthostasis. The results of the study showed that prolonged orthostasis modulated electroencephalographic waves with right leg orthostasis characterised by increased alpha wave frequency and increased EEG fatigue index.

Keywords: orthostasis; unipedal; electroencephalogram; exertional distress; rate of perceived exertion

1.0 INTRODUCTION

Orthostasis, defined as standing upright, has long been identified as a stressor (Platts et al., 2014). During upright tilt, hemodynamic changes take place in blood circulation and distribution. For example, at least 0.75L of blood, representing at least 10% of blood volume is pooled into the lower extremities during sudden standing from a reclining position (Barrette et al., 2010). This orthostasis-induced hemodynamics can compromise central blood volume, stroke volume and cardiac output and culminates in tissue perfusion shortage. One of the likely aftermaths of this change is dizziness and syncope (Platts et al., 2014). Dizziness and syncope are outcomes of severe decrement in cardiac output to the brain, decreased cerebral perfusion and the inability of cerebral autoregulatory mechanisms to defend basic cerebral perfusion requirements (Claydon et al., 2006). Therefore, several physiological mechanisms have to be activated to avert gravitational stress-induced central blood volume deprivation. For instance, the central nervous system's ischemic response is a protective reflex that swerves into action in a severe shortage of blood supply to the brain. This reflex works by inducing an increase in total peripheral resistance, thus increasing blood pressure. A group of pressure- and stretch-sensitive receptors known as baroreceptors are located in the arteries, and the heart plays important roles in their resting state as far as response to a fall in central blood volume is concerned (Barrette et al., 2010). Specifically, these receptors are involved in rapid and acute protective responses to dwindling central blood volume orchestrated by gravitational stress.

In prolonged standing, chronic exposure to standing stress occurs. Hence, in addition to baroreflex sensitivity, the body turns on the renin-angiotensin-aldosterone system, a hemodynamic regulatory and compensatory mechanism which operates to salvage the central blood volume (Barrette et al., 2010). Decreased cerebral perfusion will also elicit an increase in arginine vasopressin secretion from the supraoptic nucleus of the hypothalamus and neurohypophysis. Arginine vasopressin signals the kidney, intestine, sweat gland and salivary gland to conserve water by increasing water reabsorption and absorption and minimising water loss (Barrette et al., 2010). The ability to withstand gravitational stress, known as orthostatic tolerance, centres on the effectiveness of baroreflex and many factors influence it. For example, women exhibit lower orthostatic tolerance than males (Grenon et al., 2006; Platts et al., 2014) due to lower muscle sympathetic activity and baroreflex sensitivity. In old age, orthostatic tolerance is reduced (Mellingsæter et al., 2015), probably due to reduced renin-angiotensin-aldosterone system (RAAS) activation (Gunay and Dokuzlar, 2021).

Studies also abound on various ways of improving orthostatic tolerance. For instance, in patients with orthostasis-related syncope, water ingestion improved orthostatic tolerance and the tendency to withstand gravitational or orthostatic stress. Claydon et al. (2006) showed that consumption of 0.5L of water orchestrated a reduction in orthostasis-induced suppression in venous return but increased peripheral resistance and blood pressure. Schroeder et al. (2002) showed that intake of 0.5L of water enhanced orthostatic tolerance by about five minutes, increasing dorsal decubitus mean arterial pressure with increased blood and heart rate. Olatunji et al. (2011) also reported that consuming 0.5L of water abolished the suppression of pulse pressure and heart rate. A stronger correlation was reported between orthostatic tolerance and diastolic blood pressure in males than in females. Young and Mathias (2004) claimed to record a rise in seated blood pressure and standing blood pressure at 15 and 35 minutes after water consumption more than before water intake. Usman et al. (2015) reported that oral glucose ingestion with Vitamin C enhances orthostatic tolerance. In idiopathic orthostatic intolerance patients, water consumption abolished adverse orthostatic outcomes.

Unipedal orthostasis means standing on one leg. The time it takes to stand on one foot without swaying has been extensively devised as a simple, non-invasive index of balance postural stability in a static situation (Springer et al., 2007). In old age, unipedal stance is markedly impaired (Mizrahi et al., 1989; Jonsso et al., 2004). Conditions such as traumatic brain injury (Black et al., 2000) and craniocerebral injury (Adeniyi et al., 2020) are associated with impaired unipedal stances. Beyond being used in evaluating balance and posture, much still needs to be known about unipedal orthostasis. Many works have documented the effect of prolonged bipedal orthostasis on physiological functions (Olatunji et al., 2011; Usman et al., 2015). The study aimed to investigate the impact of prolonged unipedal orthostasis on electroencephalographic indices.

2.0 MATERIALS AND METHODS

2.1 Study design

The work was carried out in the Technologically Enhanced Laboratory unit of the Department of Physiology, College of Medical Sciences, Edo State University Uzairue, situated in Etsako West Local Government Area of Edo State, Nigeria.

2.2 Participants

A total of 30 young adult males were recruited for the study using respondent-driven sampling. Twenty apparently healthy young males averaging 18.5 years satisfied the inclusion criteria and were selected for the study. Ethical clearance was obtained from the Ethical Committee, Edo State University Iyamho.

2.3 Inclusion and exclusion criteria

Written consent was obtained from each subject, and a well-structured questionnaire was administered to rule out those with a medical history of respiratory diseases, cardiovascular, kidney, hepatic and metabolic diseases or anatomical deformities. History of smoking, alcoholism and caffeine and any form of medication was also taken. Medical examination and physical activity status evaluation were also done. Physical examinations were also performed, and those that were not medically fit were disqualified. For example, those with musculoskeletal abnormalities, and high blood pressure, among others, were ruled out. Subjects between ages 16 and 20, physical assessment score > 36%, male gender, systolic blood pressure (90-119), systolic blood pressure (60-80), pulse rate (60-100BPM) and respiratory rate (12-20 cycles/min) were considered.

2.4 Experimental protocol

The study was done in the Physiology Laboratory at a temperature of 25°C between 8.00 am and 10.00 am. The participants were acquainted with the experimental procedure, including the performance of unipedal orthostatic tolerance and how to feel exertion. They were asked to relax for 10 minutes. Resting blood pressure, pulse rate and anthropometrical data such as weight, height, and body mass index were measured as mean± standard error of the mean.

Determination of Anthropometrical Indices

Body weight was measured using a weighing scale (Hanson, China) to the nearest 0.5kg. Height was measured using the meter rule, and the meter rule was calibrated in inches. The BMI of each subject was calculated using the formula Weight in (kg)/square of metric height.

Determination of unipedal orthostasis tolerance time

With shoes off, the total time taken to stand on each limb was determined using a stopwatch. Each participant assumed unipedal posture from the sitting position without swaying. The stopwatch was started when the participants stood up with the foot and were stopped at the first perception of exertion in the foot (with a 'stop' command).

Exertional Distress Determination

In a sitting recovery position, the participants were administered a perceived exertion questionnaire (Borg Scale). The scale (6-20) was designed to measure physical discomforts (such as pedal pain, psychosomatic changes, headache or dizziness) experienced during exertional activities. They were asked to complete the rated perceived exertion questionnaire before proceeding to the second foot.

Measurement of Electroencephalographic waves

Electroencephalographic (EEG) waves were recorded using Powerlab 26T (ADInstruments PTY, Australia). As stipulated in the procedure, white and blue marked electrodes were connected to the left and right side of the frontal part of the skull while the black electrode was attached to the occiput. Electrodes were held in place using electrode pads as a part of the measures to prevent artefacts and ambient noise interference. Baseline (EEG) readings were taken in a sitting position. EEG recordings were also obtained for each right and left leg at the point of exertional distress.

Determination of EEG fatigue index

The alpha/beta ratio was calculated by dividing alpha frequency by beta frequency.

Measurement of blood pressure

Blood pressure was measured from the arm, an inch above the elbow, using a light and automated Omron BP7000 Evolve Wireless Upper Arm Sphygmomanometer (Iris Global Care, China). As previously reported, baseline readings were taken in a sitting position (Oni and Adeniyi, 2017). Blood pressure measurements were obtained for each of the legs at the first perception of exertion. One minute after unipedal orthostasis, blood pressure measurements were also recorded.

Pulse pressure was determined by subtracting diastolic blood pressure from systolic blood pressure. Mean arterial blood pressure was obtained using; diastolic blood pressure +1/3 of pulse pressure.

2.5 Statistical analysis

Statistical analysis was conducted using Statistical Package for Social Science Students (SPSS) 23. Statistical test was done using Analysis of Variance (ANOVA) and student t-test. The correlation of variables was done using Pearson correlation. A statistically significant difference was accepted at $P<0.05$.

3.0 RESULTS

3.1 Anthropometrical and physical characteristics of the subjects

The weight, height, BMI, age and percentage of handedness were estimated (**Table 1**).

Table 1: Physical characteristics of the subjects

Parameters	Mean ± SEM
Weight (kg)	56.67 ± 2.04
Height (m)	1.66 ± 0.01
BMI (kg/m^2)	19.84 ± 0.57
Age (yr)	21.50 ± 0.50
% Hand Preference	100.00 ± 0.00 (right-handed)

3.2 Effect of prolonged unipedal orthostasis on electroencephalogram

Left leg orthostasis exhibited significantly lower alpha wave amplitude when compared with right leg orthostasis. In each leg, during prolonged unipedal orthostasis, alpha wave amplitude reduced significantly compared with the baseline (**Figure 1a**). During prolonged unipedal orthostasis, alpha wave frequency significantly increased in the right leg compared to the baseline. In the right leg, during prolonged unipedal orthostasis, alpha wave frequency increased significantly compared with the left leg (**Figure 1b**).

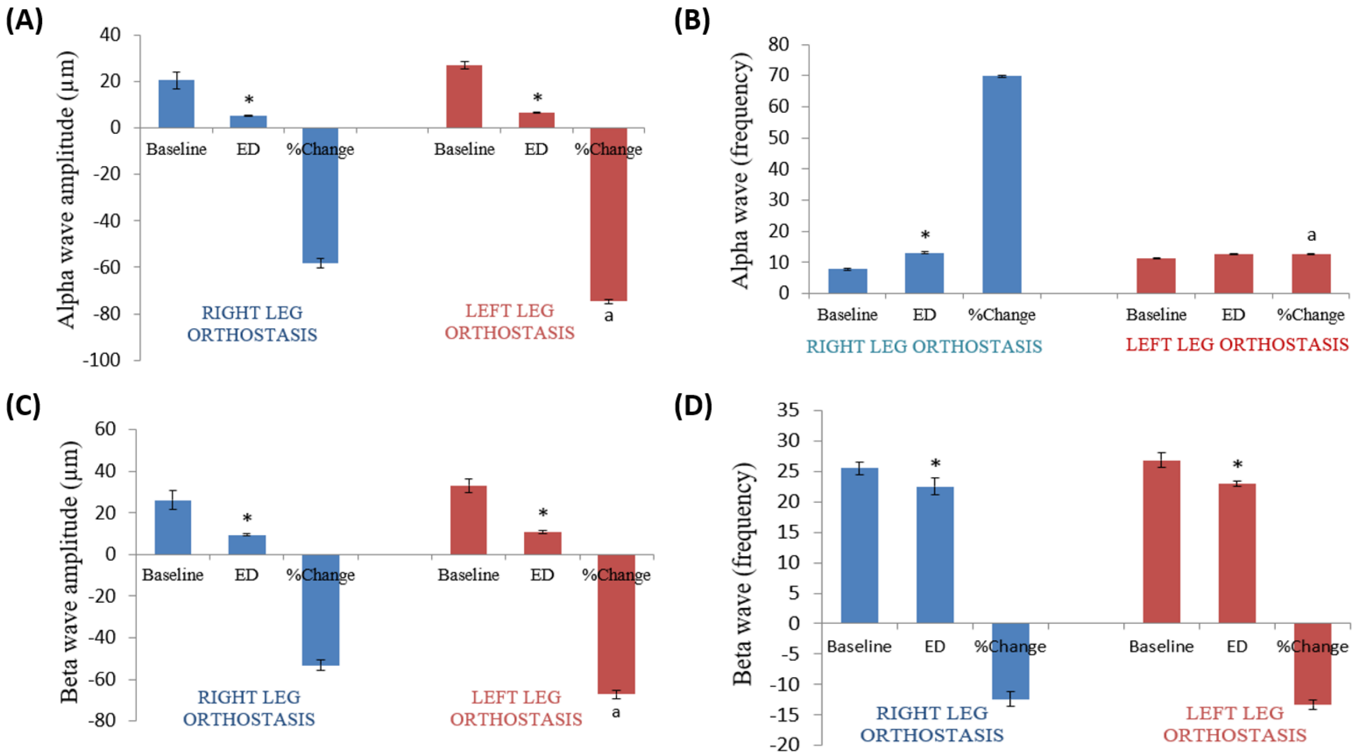

Figure 1: (A) Effect of prolonged unipedal orthostasis on alpha wave amplitude and **(B)** frequency, and **(C)** beta wave amplitude and **(D)** frequency (Hz). '*' and 'a' represent significant differences (P<0.05) from baseline and Right Leg, respectively. 'ED' stands for exertional distress.

Left leg orthostasis exhibited significantly lower beta wave amplitude when compared with right leg orthostasis. In each leg, during prolonged unipedal orthostasis, beta wave amplitude decreased significantly compared with the baseline (**Figure 1c**). In each leg, during prolonged unipedal orthostasis, beta wave frequency reduced significantly compared to the baseline (**Figure 1d**).

3.3 Effect of prolonged unipedal orthostasis on cardiovascular parameters

Systolic blood pressure was significantly increased during prolonged unipedal orthostasis in both legs. Left leg unipedal orthostasis showed significantly higher systolic blood pressure, diastolic blood pressure and pulse pressure when compared to the right leg. At 1 minute recovery, systolic, diastolic, pulse, and mean arterial blood pressure were significantly higher than baseline values.

Table 2: Effect of prolonged unipedal orthostasis on cardiovascular parameters

Cardiovascular Parameters	Groups	Baseline (Mean ± SEM)	Exertional Distress (Mean ± SEM)	1 min-Recovery (Mean ± SEM)
SBP (mmHg)	Right leg orthostasis	104.75 ± 0.32	119.00 ± 0.32*	110.00 ± 0.00*
	Left leg orthostasis	105.50 ± 0.47	121.00 ± 0.95* [a]	111.00 ± 0.67*
DBP (mmHg)	Right leg orthostasis	67.00 ± 0.32	80.00 ± 0.63*	71.00 ± 0.67*
	Left leg orthostasis	68.50 ± 0.47	76.00 ± 0.63*[a]	71.00 ± 0.67
Pulse Pressure (mmHg)	Right leg orthostasis	37.75 ± 0.63	39.00 ± 0.95*	39.00 ± 0.67*
	Left leg orthostasis	39.00 ± 0.00	45.00 ± 0.32*[a]	40.00 ± 2.67
Mean Arterial Blood Pressure (mmHg)	Right leg orthostasis	79.58 ± 0.11	93.00 ± 0.32*	84.00 ± 0.30*
	Left leg orthostasis	81.50 ± 0.47	91.00 ± 0.74*	84.33 ± 0.07*

* P<0.05 from baseline, [a] P<0.05 from Right Leg

Apart from mean arterial blood pressure, systolic blood pressure, diastolic blood pressure and pulse pressure taken during left leg orthostasis were higher than right leg values (**Table 2**).

3.4 Effect of prolonged unipedal orthostasis on electroencephalographic fatigue indices

Right leg orthostasis exhibited a significantly higher alpha/beta ratio when compared with left leg orthostasis. In each leg, during prolonged unipedal orthostasis, the alpha/beta ratio increased significantly compared with the baseline (**Figure 2**).

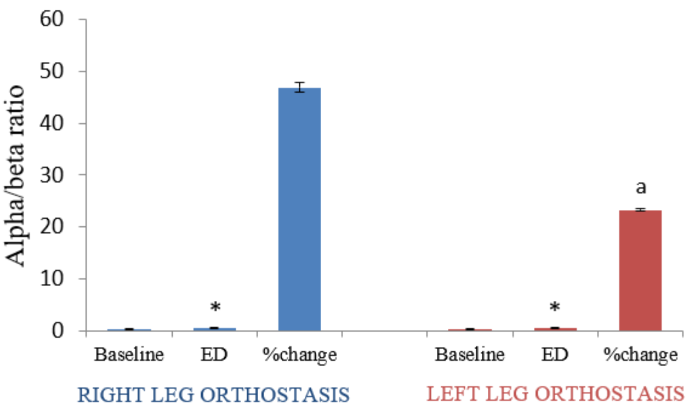

Figure 2: Effect of prolonged unipedal orthostasis on alpha/beta ratio. * represents a significant difference (P<0.05) from baseline. 'a' represents a significant difference from Right Leg. 'ED' stands for exertional distress.

3.5 Effect of prolonged unipedal orthostasis on the rate of perceived exertion

In each leg, prolonged unipedal orthostasis caused a significant increase in the rate of perceived exertion when compared with the baseline (**Table 3**).

3.6 Effect of prolonged unipedal orthostasis on orthostatic tolerance time

In each leg, during prolonged unipedal orthostasis, prolonged orthostasis caused a significant increase in orthostatic tolerance time compared with the baseline (**Table 4**).

3.7 Correlation between rate of perceived exertion and EEG fatigue index

The rate of perceived exertion correlated positively with the alpha/beta ratio. Coefficients of correlation were stronger during right leg orthostasis (**Table 5**).

3.8 Correlation between orthostatic tolerance time and EEG fatigue index

Orthostatic tolerance time correlated positively with the alpha/beta ratio. Coefficients of correlation were stronger during right leg orthostasis (**Table 6**).

3.9 Correlation between blood pressure and EEG fatigue index

Systolic blood pressure correlated positively with the alpha/beta ratio. The correlation coefficient was stronger during right leg orthostasis (**Table 7**).

Table 3: Effect of prolonged unipedal orthostasis on the rate of perceived exertion

Groups	Baseline	Exertion Distress
Right leg orthostasis	0.00±0.00	17.00 ± 1.47*
Left leg orthostasis	0.00±0.00	16.67 ± 1.70*

*P<0.05 from baseline

Table 4: Effect of prolonged unipedal orthostasis on orthostatic tolerance time (minutes)

Groups	Baseline	Exertion Distress
Right leg orthostasis	0.00±0.00	6.00±0.71*
Left leg orthostasis	0.00±0.00	6.333±1.25*

*P<0.05 from baseline

Table 5: Correlation between rate of perceived exertion and EEG fatigue index

R	alpha/beta ratio
Rate of perceived exertion (Right leg orthostasis)	.922*
Rate of perceived exertion (Left leg orthostasis)	.786*

*P<0.05

Table 6: Correlation between orthostatic tolerance time (minutes) and EEG fatigue index

R	alpha/beta ratio
Orthostatic tolerance time (Right leg orthostasis)	.948*
Orthostatic tolerance time (Left leg orthostasis)	.782*

*P<0.05

Table 7: Correlation between blood pressure (mmHg) and EEG fatigue index

R	alpha/beta ratio
Systolic Blood Pressure (Right leg orthostasis)	.916*
Systolic Blood Pressure (Left leg orthostasis)	.808*
Diastolic blood pressure (Right leg orthostasis)	.980*
Diastolic blood pressure (Left leg orthostasis)	.767*

*P<0.05

4.0 DISCUSSION

Orthostatic stress is a common stressor (Black et al., 2000). The body's tendency to cope with the stress-inducing condition depends on the functional status of neurovascular reflexes and health status, among other factors (Platts et al., 2014). The result of the study showed that prolonged orthostasis led to significant increases in systolic blood pressure, diastolic blood pressure, mean arterial pressure and pulse pressure from the baseline values. The increase signified the inactivation of baroreceptors due to orthostasis-induced low blood volume and low blood pressure (Barrett et al., 2010). During sudden standing, blood is pooled down to the lower extremities at the expense of central blood volume (Platts et al., 2014), resulting in a decline in baroreceptors activation with a consequent increase in total peripheral resistance and blood pressure. The relative increase in systolic blood pressure, diastolic blood pressure and pulse pressure during left leg unipedal orthostasis might be well explained by the left looping of the heart anatomically and relative proximity of the left limb to the heart. The closer a structure is to the heart, the more blood flow it will get (Barrett et al., 2010). We also noticed that at 1 minute of recovery from standing stress, systolic, diastolic, pulse, and mean arterial blood pressure were significantly higher than baseline values. This might reflect the functional status of the neurovascular reflex of our subjects. Apart from mean arterial blood pressure, systolic blood pressure, diastolic blood pressure and pulse pressure taken during left leg orthostasis were higher than right leg values. This also might be due to the anatomical position of the heart.

Scientists have quantified how long an individual can withstand gravitational stress, known as the orthostatic tolerance test (Black et al., 2000). The result of the orthostatic tolerance test showed that it takes a longer time though insignificant, to stand on the left leg when compared to the right leg. An extensive search of the literature reveals that most of the works undertaken by investigators were only designed to compare unipedal stance time between the right and left legs. In the study, only right-handed individuals were employed; therefore, it might be difficult to adduce cerebral dominance to an individual's ability to stand longer. Conversely, since the left hemisphere controls the right side of the body in right-handed individuals, body weight can be shifted to the left to compensate for the dominant right lower limb.

Rate of perceived exertion is a subjective test invented by Gunnar Borg and recommended for use in 1986 (Borg, 1998). The scale was designed to measure physical discomforts such as pedal pain, psychosomatic changes, headache or dizziness experienced during exertional activities. Unlike orthostatic tolerance time, we observed that the rate of perceived exertion was higher when standing on the right leg, though insignificant, than on the left leg. The participants may have perceived more exertion and were unable to stand for a long while on their right legs, probably because there was a shifting of body weight to the left to compensate for the dominant right lower limb. Neural impulses are transmitted from the neurons to the muscles to drive contractile activities. Electrocardiogram records electrical activities typifying voltage fluctuations within the superficial neurons of the brain (Niedermeyer and Da Silva, 2004). Beta wave amplitude decreased at the first perception of distress in individuals under prolonged orthostasis. Beta amplitude is generally known to depict the strength of cortical neural impulses due to the synchronisation of signals from multiple cortical neurons (Australian

Academy of Science, 2021). Usually, during chewing and exercise, an increase in beta wave amplitude has been recorded (Morinushi et al., 2000; Eoh et al., 2005). This is thought to be due to the involvement of multiple areas of the cerebral cortex. The decreased beta wave amplitude observed in both legs during unipedal orthostasis at the first distress perception indicated less synchronisation extent. We also observed that exertional distress decreased beta wave amplitude in the left leg when compared with the right leg. This also implies fewer synchronous cortical discharges occurred at the first perception of exertional distress in the left leg. Regarding beta wave frequency, at the first perception of exertion, beta wave frequency decreased in both legs, but no significant difference was observed between the two legs. For many years, a decrease in beta wave frequency has been reported during diminutive attention, decreased concentration, tiredness and fatigue (Eoh et al., 2005).

Increased alpha wave frequency indicates inhibition of resting or inactive visual cortical neurons by spontaneous thalamic discharge due to eye closure, light sleep, reduced attention, blinking, reductions in concentration and stimulation, and fatigue (Stern, 2005). In the study, at the first perception of exertional distress, the alpha wave was found to increase during right unipedal orthostasis. However, the right leg exhibited higher alpha wave frequency than the left leg, implying that fatigue perception occurs first at the right leg. Since the study was carried out in right-handed individuals, this result might justify why orthostatic tolerance time is longer in the left leg but shorter in the right leg in most individuals.
As earlier stated, an increase in alpha wave frequency and a decrease in beta wave frequency occur during fatigue. Simple methods, better known as the EEG fatigue index, explore alpha and beta wave frequencies for depicting fatigue (Jap et al., 2009; Adeniyi et al., 2022; Adeniyi, 2022). At the first perception of exertional distress, when compared with the baseline, the alpha wave/beta wave ratio increased in each of the legs, with right leg orthostasis showing a significantly higher value than left leg orthostasis. These findings may explain why the perception of exertional distress begins at the right leg in right-handed individuals. We observed that systolic blood pressure correlated positively with the alpha/beta ratio during right and leg orthostasis, but the correlation coefficient was stronger during right leg orthostasis. Thus, this finding highlighted how orthostatic stress influenced cortical neural activity and cardiovascular function. Thus, during prolonged right leg orthostasis in healthy adults, an increase in EEG fatigue index was associated with higher systolic blood pressure.

The stronger correlation coefficient observed in the right leg between the rate of perceived exertion and EEG fatigue index (alpha wave/beta wave ratio) also buttressed the perception of exertional distress that occurred first at the right leg in right-handed individuals. Similarly, a stronger correlation coefficient was observed in the right leg between orthostatic tolerance time and EEG fatigue index.

Even though the work was limited to right-handlers, the study has been able to explain the effect of prolonged unipedal orthostasis highlighting which leg was more susceptible to gravitation stress-induced fatigue.

5.0 CONCLUSIONS

In conclusion, the results of the study showed that prolonged unipedal orthostasis modulated electroencephalographic waves with right leg orthostasis characterised by increased alpha wave frequency and increased EEG fatigue index.

Acknowledgement: The authors are grateful to the Laboratory staff of Physiology Department, Edo University Iyamho.

Author contribution: M.A. was involved in the conceptualisation of the work. M.A, O.F., O.O., S.S. and C.A. were involved in the design and execution of the project.

Conflict of interest: The authors declared there was no conflict of interest.

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