Journal of Research in Applied and Basic Medical Sciences 2025; 11(1): 107-114

Original Article

Urmia University of Medical Sciences

RABMS Journal of Research in Applied and Basic Medical Sciences

Electrophysiological analysis of the upward and downward phases of squat and lying leg raise work-out

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Abstract

Background & Aims: Electrical activities are required for muscular contractions and physical activities. Understanding the electrophysiological attributes of the upward and downward phases of squats and lying leg raises provides a strong scientific basis for modifying physical exercises to suit specific fitness and rehabilitation goals. The aim of the study was to determine the effects of the upward and downward phases of squats and lying leg raise work-outs on electroencephalograms and electrocardiograms in healthy male individuals.

Materials & Methods: Ten healthy young adult males averaging 19.6 of age and meeting the inclusion criteria were selected. Squat and lying leg raise work-outs were conducted at a rate of 12 reps per minute. Electroencephalograms and electrocardiograms were recorded using the PowerLab 26T system.

Results: The study results showed that during the downward phase of squat work-outs, beta wave frequency was higher compared to the downward phase of lying leg raise work-outs. Both the upward and downward phases of squat work-outs caused a reduction in alpha/beta and alpha wave frequencies compared to the corresponding upward and downward phases of lying leg raise. Additionally, the downward phase of squats resulted in a lower RR interval than the upward phase.

Conclusion: The findings of the study highlighted the electroencephalographic and electrocardiographic characteristics of the upward and downward phases of squat and lying leg raise work-outs in healthy male individuals. Compared to the downward phase of lying leg raises, the downward phase of squats was characterized by higher beta wave frequency, lower alpha wave frequency and a lower alpha/beta ratio. The downward phase of squats elicited greater cortical activation relative to lying leg raises.

Keywords: Alpha wave, Beta wave, Electrophysiology, Lying leg raise, RR interval, Squat

Received 14 September 2024; accepted for publication 03 December 2024

Introduction

Routine daily activities, including toileting and transitioning from a sitting to a standing position and vice versa, involve squatting (1, 2). As a resistance work-out, squatting requires lowering the hips from a standing position (downward phase) and returning to the standing position (upward phase). Typically, the downward phase involves flexion of the knee and hip joints, dorsiflexion, and eccentric contractions of the gluteus maximus and quadriceps. In contrast, the upward phase requires plantarflexion, knee and hip extensions and concentric contractions of the gluteus maximus and quadriceps. Thus, squatting is ideal for strengthening the hip and knee extensors.

As one of the most commonly prescribed rehabilitative exercises, its intensity can be modified, usually through adjustments in depth, repetitions, and the inclusion of free weights. Front and back squats are examples of squat modifications. When comparing the muscular activity elicited by front and back squats, Yavuz et al. (2015) (3) reported high electromyographic activity in the vastus medialis during the ascending phase of front squats and in the semitendinosus during the ascending phase of back squats. Gullett et al. (2009) (4) showed that back squats caused greater knee extensor movements and compressive force compared to front squats, implying a relative advantage of front squats for individuals with knee complications.

Similar to squatting, the lying leg raise consists of an upward phase during which both legs are raised from the starting position and a subsequent downward phase. In a study by Beales et al. (2009) (5), lying leg raises were associated with increased intra-abdominal pressure and depression of the pelvic floor compared to an active straight leg raise. Beales et al. (2010) (6) differentiated between subjects, finding that individuals with pelvic girdle pain and pain-free subjects exhibited differences, with pelvic girdle pain subjects possessing aberrant motor control patterns during an active straight leg raise. Increased motor activity was also shown to be associated with higher intra-abdominal pressure shifts in baseline during leg lifting with inspiratory resistance (6).

During squatting and lying leg raises, profound changes occur in body functions. In undergraduate students, Chukwuemeka et al. (2024) (7) examined the effect of squatting on heart rate and blood pressure in 35 males and 40 females. Compared with pre-exercise lying, post-exercise squatting blood pressure and heart rate in the first and second minutes were significantly different. In diabetics, squatting from a sitting position caused higher blood pressure compared to non-diabetics, while standing from a squatting position elicited a greater blood pressure reduction in diabetic individuals (8). In 160 diabetic patients, pulse pressure and pulse rate were found to be higher in diabetic individuals in a squatting position when compared to healthy individuals. Squatting-induced abnormal cardiovascular autonomic indices were also reported with increasing age in diabetic patients (9). Yoo (2017) (10) developed a modified active leg raise work-out characterized by neck flexion over 2 weeks, which was utilized for the management of lumbar lordosis and low back pain.

The advent of modern simple non-invasive polygraph techniques has made recording of electrophysiological changes, including electroencephalograms and electrocardiograms (ECG) during physical exertions (11-13), as well as during the upward and downward phases of strength training more feasible. The aim of the study was to determine the effects of the upward and downward phases of squat and lying leg raise work-outs on electroencephalograms and ECG in healthy male individuals.

Materials & Methods

Study Design

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

Participants

Twenty young individuals were recruited for the study through respondent driven sampling. Ten healthy young adult males who satisfied the inclusion criteria were selected. The average age of the participants was 19.6 years. Written consent was obtained from each participant.

Inclusion Criteria

Male participants were recruited for the study. Blood pressure, pulse rate and respiratory rate were assessed. Participants whose systolic blood pressure, diastolic blood pressure, pulse rate, and respiratory rate ranged from 90 mmHg to 119 mmHg, 60mmHg to 80mmHg, 60bpm to 100bpm, and 12cycles/min to 20cycles/min, respectively, were included, as previously reported (14-17).

Exclusion Criteria

A well-structured questionnaire was administered to exclude individuals with a medical history of smoking, alcoholism, caffeine intake, or the use of any form of medication. Participants with kidney, hepatic, or metabolic diseases, as previously reported (18-21), were also excluded. Additionally, individuals with a history of respiratory and cardiovascular diseases, blood pressure, pulse rate, or and respiratory rates outside the normal range, as well as those who were underweight, overweight, or obese, were exempted. Participants with anatomical deformities or those who had participated in any programmed physical activities in the past 3 months were not included in the study.

Execution of Squat and Lying Leg Raise Work-outs

Before the commencement of the experiment, participants were trained on the procedures for performing the squat and lying leg raise work-out programs. They were instructed to exhale during the downward phases of the squat and lying leg raises. Each work-out (both upward and downward phases) was performed at a rate of 12 reps per minute.

Determination of Electroencephalographic Waves

Electroencephalographic (EEG) waves were recorded using the PowerLab 26T system (ADInstruments PTY, Australia). Following the procedure, both white and blue-marked electrodes were connected to the left and right sides of the frontal part of the skull while the black electrode was attached to the occiput. Electrodes were held in place using electrode pads. To prevent artifacts, ambient noise interference and movements unrelated to the work-outs were avoided. Electrode pads were tightly secured to the designated parts of the scalp with paper tape to prevent displacement during movement.

Baseline EEG readings were taken in a sitting position. EEG recordings were also obtained during the upward and downward phases of the squat and lying leg raise programs.

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

Determination of Electrocardiographic Waves

ECG were recorded using PowerLab 26T (Adinstruments PTY, Australia). The recording were done using an isolated input amplifier (BioAmp) connected to a five-electrode cable. Following the guidelines, three electrodes were connected to the left leg (positive electrode), right leg (neutral electrode), and right arm (negative electrode).

Baseline ECG readings were taken in a sitting position. ECG recordings were also obtained during the upward and downward phases of the squat and lying leg raise programs.

Results

Electroencephalographical Effect of Upward and Downward Phases of Squat and Lying Leg Raise

Figure 1 shows the effect of the upward and downward phases of the squat and lying leg raise on alpha wave frequency. The upward and downward phases of the squat caused a significant decrease in alpha wave frequency when compared with the baseline. The upward phase was significantly different from the downward phase of the lying leg raise. There was a significant difference between the upward phase of the squat and the upward phase of the lying leg raise. The downward phase of the squat was significantly different from the downward phase of the lying leg raise.

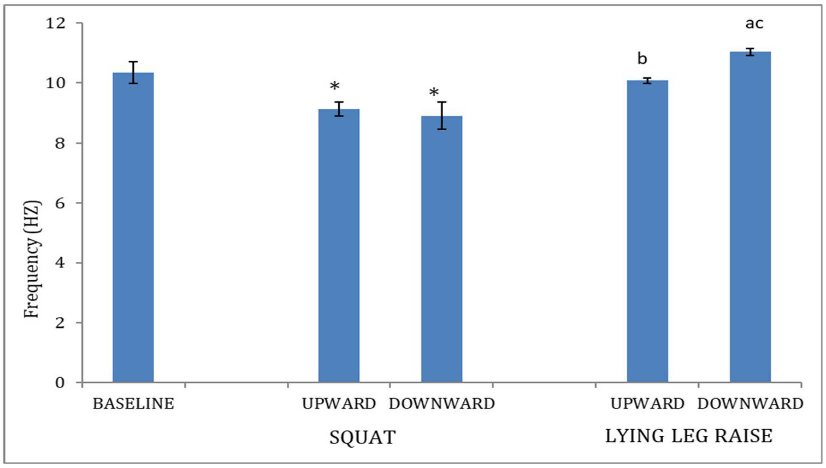

Fig. 1. Effect of Upward and Downward Phases of Squat and Lying Leg Raise on Alpha Wave Frequency. * Represents a Significant Difference ($P < 0.05$) from Baseline; [a] Represents Significant Difference ($P < 0.05$) between Upward and Downward Phases; [b] Represents Significant Difference ($P < 0.05$) between Upward Phase of Squat and Upward Phase of Lying Leg Raise; [c] Represents Significant Difference ($P < 0.05$) between Downward Phase of Squat and Downward Phase of Lying Leg Raise.

Figure 2 shows the effect of upward and downward phases of the squat and lying leg raise on beta wave frequency. There was a significant difference between downward phases squat and lying leg raise.

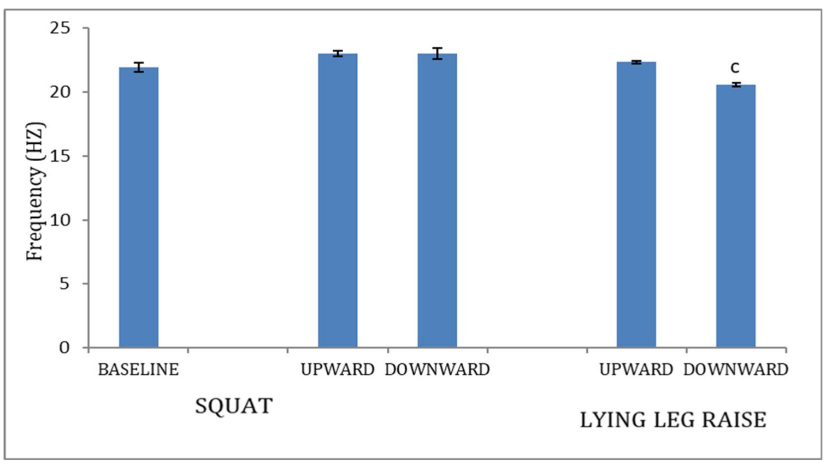

Fig. 2. Effect of upward and downward phases of squat and lying leg raise on beta wave frequency. [c] represents significant difference ($P < 0.05$) between downward phase of squat and downward phase of lying leg raise.

Figure 3 shows the effect of the upward and downward phases of the squat and lying leg raise on the alpha/beta ratio. The upward and downward phases of the squat caused a significant decrease in the alpha/beta ratio when compared with the baseline. The upward phase was significantly different from the downward phase of the lying leg raise. There was a significant difference between the upward phase of the squat and the upward phase of the lying leg raise. There was also a significant difference between the downward phase of the squat and the downward phase of the lying leg raise.

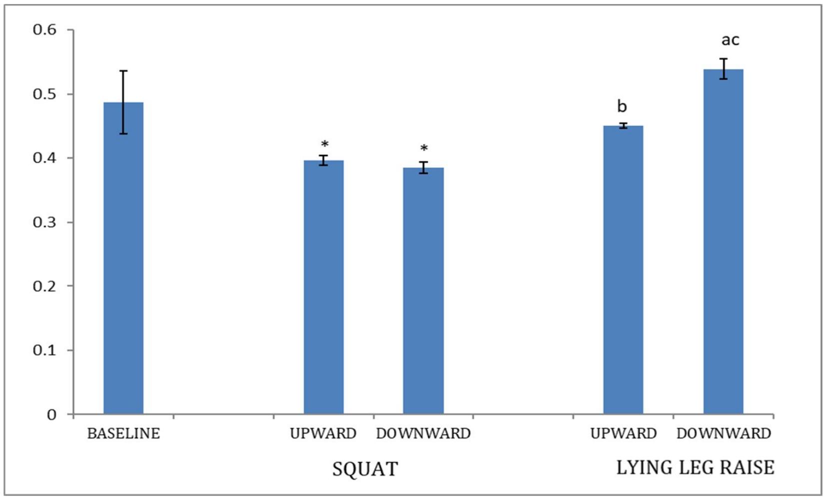

Fig. 3. effect of upward and downward phases of squat and lying leg raise on alpha/beta ratio; * represents significant difference ($P < 0.05$) from baseline; [a] represents significant difference ($P < 0.05$) between upward and downward phases; [b] represents significant difference ($P < 0.05$) between upward phase of squat and upward phase of lying leg raise; [c] represents significant difference ($p < 0.05$) between downward phase of squat and downward phase of lying leg raise.

Electrocardiographic Effect of Upward and Downward Phases of Squat and Lying Leg Raise

Table 1 shows the electrocardiographic effect of upward and downward phases of squat and lying leg raise. When compared with baseline, downward phase of squat and upward and downward phases of lying leg raise significantly reduced RR interval ($P < 0.05$). RR interval was lower during downward phase when compared with upward phase. R wave amplitude was lower during downward phase of lying leg raise when compared with baseline and lower in downward phase of lying leg raise when compared with downward phase of squat. Upward phase of lying leg raise was lower than upward phase of squat.

Table 1. Effect of the upward and downward phases of the squat and lying leg raise on the electrocardiogram

Parameters	Baseline	Squat		Lying leg raise	
		Upward	Downward	Upward	Downward
RR interval (S)	0.798 ± 0.02463	0.770 ± 0.00655	0.720 ± 0.00218*[a]	0.745 ± 0.00109*	0.755 ± 0.01418*
R wave amplitude (MV)	0.815 ± 0.02907	0.840 ± 0.01159	0.812±0.01689	0.7815 ± 0.00687[b]	0.7434 ± 0.02513*[c]
S wave amplitude (MV)	0.293 ± 0.04322	0.247 ±0.01026	0.288 ± 0.01909	0.2415 ± 0.01058	0.235 ± 0.00896

Tab. 1. Effect of Upward and Downward Phases of Squat And Lying Leg Raise on the Electrocardiogram;* Represents Significant Difference ($P < 0.05$) from Baseline; [a] Represents Significant Difference ($P < 0.05$) between Upward and Downward Phases; [b] Represents Significant Difference ($P < 0.05$) between Upward Phase of Squat and Upward Phase of Lying Leg Raise; [c] Represents Significant Difference ($P < 0.05$) between Downward Phase of Squat and Downward Phase of Lying Leg Raise.

Discussion

Previous studies have explored the biomechanical activities that occur during various strength training exercises using electromyography, an electrophysiological technique (3, 4). There is a preponderance of comparative studies designed to highlight differences in energy expenditure, suitability for rehabilitation and fitness goals, and management of musculoskeletal injuries using electromyography (5, 6). However, studies analyzing the electrophysiology of the upward and downward phases of strength training work-outs are limited.

One of the major findings of the study was that alpha wave frequency was lower during both the upward and downward phases of squat work-outs when compared to the baseline, unlike in the lying leg raise. Alpha wave is known to be prominent during relaxed wakefulness with eyes closed, as well as during fatigue and dizziness. This suggests that the upward and downward phases of squats were associated with relatively higher alertness compared to the baseline. There was no significant difference in alpha wave frequency between the upward and downward phases of squat, implying that alertness during these phases was comparable. However, when the upward and downward phases of squats were compared with the respective phases of lying leg raises, alpha wave frequency was lower during squats, indicating relatively higher alertness.

Beta wave frequency increases during cortical activation as well as mental and physical activities. Discharges from the motor cortices are necessary for the execution of skeletal muscle changes that occur during physical exertion (11, 22-24). In this study, neither squats nor lying leg raises caused a significant effect on beta wave frequency compared to the baseline. However, the downward phase of squat work-outs exhibited a higher beta wave frequency compared to the downward phase of lying leg raises. This suggests that the downward phase of squats is more demanding than the downward phase of lying leg raises. During the downward phase of squats, eccentric contractions of the gluteus maximus and quadriceps occur, alongside the lowering of body weight by the hips. In contrast, the downward phase of lying leg raises does not involve bearing body weight.

The alpha/beta wave ratio is an EEG index of fatigue, with a relatively high alpha/beta ratio signifying fatigue (11, 13, 25, 26). An increase in alpha wave frequency or a decrease in beta wave frequency, arithmetically, will lead to a high alpha/beta ratio. In the study, both the upward and downward phases of the squat caused lower alpha wave frequency compared to the baseline. The upward and downward phases of the lying leg raise work-out produced a higher alpha/beta ratio, signifying lower visual cortical activation compared to the upward and downward phases of the squat, respectively.

A plethora of evidence suggests that squatting from a sitting position profoundly impacts cardiovascular function in both health and disease (7-9). The RR interval, defined as the duration between two successive R waves, is inversely related to heart rate. In the study, the lower RR interval observed during the downward phase of the squat compared to the baseline indicated an increase in heart rate during this phase. The downward phase of the squat also resulted in a lower RR interval than the upward phase. Furthermore, both the upward and downward phases of the lying leg raise work-out resulted in lower RR interval compared to the baseline, with no significant difference between the two phases.

In addition to the RR interval, the R wave amplitude reflects the size of the ventricles. During the downward phase of the lying leg raise work-out, the R wave amplitude was lower compared to the baseline. Moreover, the upward and downward phases of the lying leg raise were associated with lower R wave amplitudes than the corresponding phases of the squat work-out. The findings of the study provide a strong scientific basis for modifying physical exercises to suit specific fitness and rehabilitation goals. Along with pre-exercise medical fitness status, adequate consideration should be given to physically and medically unfit patients and older individuals when prescribing work-outs.

Conclusion

In conclusion, the findings of the study indicated the EEG and electrocardiographic characteristics of the upward and downward phases of squat and lying leg raise work-outs in healthy male individuals. Compared to the downward phase of the lying leg raise, the downward phase of the squat was characterized by high beta wave frequency, low alpha wave frequency, and a low alpha/beta ratio. The downward phase of the squat elicits greater cortical activation. The study highlights the significant roles of electroencephalogram and electrocardiogram recordings during work-outs to prevent exertion-induced injuries and complications. Future studies should consider the effects of modified squatting and lying leg raise programs at higher intensities on electrophysiological parameters.

Acknowledgments

The authors are grateful to all the laboratory staff.

Ethical statement

Approval and informed consent were obtained (EUI035).

Data availability

The data generated in the study are available in the figures and table.

Conflict of interest

None declared.

Funding/support

No funding was received.

Author contributions

MJA conceptualized the study. MJA, AA, SAA, JO, SI, and PNK contributed to the manuscript preparation.

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