THE DIFFERENCE OF CORE MUSCLE ACTIVITY PRODUCED DURING SUSPENSION TRAINING EXERCISES OF UPPER AND LOWER EXTREMITIES IN HEALTHY ADULTS: A CROSS SECTIONAL STUDY

by

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in

Sports

Under the guidance of

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2022 - 2024

DECLARATION BY THE CANDIDATE

I hereby declare that this dissertation/thesis entitled "**THE DIFFERENCE OF CORE MUSCLE ACTIVITY PRODUCED DURING SUSPENSION TRAINING EXERCISES OF UPPER AND LOWER EXTREMITIES IN HEALTHY ADULTS: A CROSS SECTIONAL STUDY"** is a bonafide and genuine research work carried out by me under the guidance of **Dr Chinmaya Patra.**

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ABSMARI

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~ Shree Krishna Sada Sahayateh ~

LIST OF ABBREVATIONS USED

1	**ASIS**	Anterior superior iliac spine
2	**BOS**	Base of support
3	**COM**	Centre of mass
4	**EMG**	Electromyography
5	**EO**	External oblique
6	**ES**	Erector spinae
7	**IO**	Internal Oblique
8	**MVIC**	Maximum voluntary isometric contraction
9	**% MVIC**	Percentage of maximum voluntary isometric contraction
10	**RA**	Rectus abdominis
11	**RMS**	Root mean square
12	**ROM**	Range of motion
13	**sEMG**	Surface electromyography
14	**SENIAM**	Surface electromyography for the non-invasive assessment of muscles
15	**SL**	Suspended Lunge
16	**ST**	Suspension Training
17	**TRX**	Total body resistance exercise
18	**TYF**	TRX Y Fly

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ABSTRACT

Background: Suspension training (ST) is known to enhance core muscle activation through instability. However, there is limited research comparing how upper versus lower extremity ST exercises affect core muscle activation. This study examines these differences in healthy adults.

Methods: Core muscle activation, including the rectus abdominis (RA), external oblique (EO), internal oblique (IO), and erector spinae (ES), was measured during selected upper and lower extremity ST exercises using surface electromyography (sEMG). Participants completed TRX Y Fly (TYF) and Suspended Lunge (SL) exercises, and the sEMG data were analyzed to compare muscle activation between the two types of exercises.

Results: Differences in core muscle activation were found between upper and lower extremity ST exercises. Upper extremity exercises showed greater activation of the RA ($p < 0.05$), EO ($p = 0.05$) and ES ($p < 0.05$) while lower extremity exercises led to increased activation in the IO ($p < 0.05$). These results suggest that different ST exercises target specific core muscles differently.

Conclusion: This study shows that upper and lower extremity ST exercises activate core muscles differently, underlining the importance of exercise choice in ST programs. These findings can help design targeted training routines to improve core stability, enhance performance, and reduce injury risk.

KEYWORDS: Core muscles, electromyography, instability, muscular activity, suspended lunge, suspension training, TRX Y fly

INTRODUCTION

The core serves as the central foundation for most athletic movements. When it is not functioning properly, the efficiency of force generation and transfer throughout the body is compromised.[1] Core stability training or core strengthening is a well-recognised fitness trend gaining popularity into the field of sports medicine.[2] Anatomically, the core region has been described as the area bounded by the abdominal muscles in the front, by paraspinal and gluteal muscles in the back, by diaphragm on the top and by pelvic floor and hip girdle musculature at the bottom.[3] The core serves as the link between the lower and upper limbs and should be regarded as a functional unit where various muscles interact, regardless of their location outside the thoraco-lumbar region, such as shoulder and pelvic muscles.[4] In this particular region, there are 29 pairs of muscles that contribute to stabilizing the spine, pelvis, and kinetic chain during functional movements.[2] The core muscles are particularly important because they provide "proximal stability for distal mobility." In biomechanically effective movements aimed at minimizing joint loading, proximal stabilization must precede the movement of the distal extremities,[5] thereby improving the stability of the movement.[6]

Core muscles can be categorized as global and local units, depending on their position within the core region and their attachment sites. Muscles originating or inserting at the vertebrae, excluding the psoas, are part of the local system. This system controls curvature, provides sagittal and lateral stiffness, ensuring lumbar spine stability.[7] Primarily composed of slow-twitch fibers, these muscles are shorter and adept at managing intersegmental motion and adapting to posture and external loads.[2] The global system includes active components like muscles and intra-abdominal pressure, transferring load directly between the thoracic cage and pelvis. Muscles such as the global erector spinae, internal and external obliques, rectus abdominis, lateral quadratus lumborum, and the psoas are involved. The global system responds to changes in external load direction, while the local system adjusts to lumbar spine posture changes.[7] Effectively controlled local muscles can maintain optimal alignment of spinal segments, potentially reducing unnecessary strain on global muscles.[8]

Resistance training effectively improves multiple key factors related to physical and mental well-being.[9] Conventional strength training with external load concentrates on targeting particular muscle groups.[10] Progress in understanding the specific demands of sports has led to the creation of training methodologies that incorporate innovative functional criteria.[10] As a result, recent training trends aim to maximize muscle activation during sport-specific movements and to bolster accessory muscle strength by emphasizing movements across multiple planes.[11] Coaches, athletes, and fitness enthusiasts aim to increase training challenges by varying exercise complexity, adjusting instability and intensity levels.[12] Strength training on unstable surfaces or with unstable implements significantly enhances instability compared to stable conditions, promoting superior neuromuscular adaptations.[12,13] In recent years, integrating instability into traditional exercises has gained popularity for enhancing core muscles, improving balance, proprioception, and overall performance.[13–18] Suspension training has emerged as a contemporary strategy designed to introduce instability and enhance muscle activation.

“Suspension training (ST) is defined as having one or more straps connected to point as the user is suspended from the handles of the straps by either their hands or feet, while the non-suspended pair of extremities are in contact with the ground” as described by Harris et al.[19] ST enhances motor unit recruitment using the concepts of body weight and force momentum. The degree of instability induced by the suspension device and the body position determines the difficulty of the ST exercise and the number of motor units recruited.[10] Multi-planar, multi-joint movements are used in this sort of training against gravity while using the body's own weight as resistance. One or both limbs are supported during exercise by handle straps (or cradles) at the ends of a suspension cable with a single above-head anchor point, such as a ceiling or wall[20] and thus, due to the unstable base of support (BOS), ST alters how the muscles are recruited.[19] Total body resistance exercise (TRX) is a traditional suspension device with the main strap's bottom having a main carabineer and a stabilizing loop where another strap can be locked, making a V shape with handles.[10] Three guiding concepts determine the load placed on the body during ST exercises[17,21]: stability principle, vector-resistance principle and pendulum principle. Suspension training necessitates increased muscle activation by manipulating three fundamental principles.[10,19]

Size and location of the base of support (BOS): By altering the size and position of the BOS relative to the user’s centre of mass (COM), ST creates an unstable platform. This instability requires muscles to engage across various amplitudes to maintain the COM over the shifting BOS.[19] Exercise intensity is influenced by the body's BOS and COM; widening the base of support enhances stability, thereby making the exercise easier, whereas narrowing it decreases stability, thereby increasing difficulty.[22]

Direction of vector forces on muscle groups: Changes in the BOS direction impacts the angles of gravitational forces exerted on muscle groups. These shifts can influence how muscles are recruited and coordinated during exercises.[19] Adjusting the angle of pull not only intensifies exercise but also alters the body's orientation relative to the ground. Increasing the lever arm, or the distance from the gravitational pull, similarly heightens exercise intensity; essentially, the greater the deviation from vertical alignment, the greater the resistance encountered.[22]

Horizontal position of the COM relative to the anchor point: ST involves placing hands or feet into cradles attached to anchored straps. The horizontal movement of these cradles induces a pendulum effect, altering the horizontal position of the COM in relation to the BOS. This adjustment dynamically changes the gravitational vectors acting on the muscles, thereby adjusting the loads experienced by the targeted muscle groups.[19]

The mechanical adjustments involved in suspension training pose significant challenges to muscle activation and coordination, essential for executing exercises effectively and maintaining stability. This demands precise neuromuscular adaptations, as individuals must manage the instability introduced by suspension systems, thereby enhancing their ability to stabilize and control movements.[4] The core muscles play a crucial role in establishing a stable foundation for the function of the extremities, facilitating the transfer of force and enabling efficient control of body movements.[1,23]

Surface electromyography (sEMG) is a primary method employed for the detection and analysis of the electrical signals generated by skeletal muscles using surface electrodes placed on the skin.[24] Surface electromyography, when combined with kinematic and kinetic data, is a valuable tool for guiding treatment decisions and developing rehabilitation protocols by evaluating neuromuscular responses during various activities.[25] Pheezee® is an advanced device with two wearable modules and a mobile app for real-time measurement of joint range of motion (ROM) and muscle activity (sEMG). It operates on rechargeable batteries, sends data to the cloud for analysis, and provides immediate results on a smartphone screen, facilitating therapy monitoring and clinical assessments.[26]

NEED FOR THE STUDY

From the available literatures this has been found that core stability is vital for optimal movement and injury prevention. Many studies have proven the effectiveness of various exercises involving spinal movements in improving core stability. Hence, this study is an attempt to explore the relationship between core muscle activation and ST exercises involving the extremities, and to determine whether these exercises contribute to the strengthening of core muscles.

The findings of the study will aid rehabilitation specialists and fitness professionals in selecting optimal suspension exercises for clients at various rehabilitation or fitness stages. By identifying the most effective exercises for core muscle activation, the study may enhance exercise prescription and outcomes for diverse individuals.

The study will validate ST as an effective method for improving core stability and recommend its use in training programs for both healthy individuals and those with musculoskeletal issues in order to enhance athletic performance and reduce injury risk by promoting effective core stability strategies through improved core muscle activation.

RESEARCH QUESTION

Whether ST exercises of the extremities affect the activation levels of core muscles in healthy adults?

AIM OF THE STUDY

To assess the differences in the activation of the core muscles while performing the ST exercises of the upper and the lower extremities.

OBJECTIVE OF THE STUDY

To observe the core muscle activity produced during ST exercises of the upper extremity.

To observe the core muscle activity produced during ST exercises of the lower extremity.

To differentiate between upper and lower extremity ST exercises on various core muscle activation.

HYPOTHESES

Null Hypothesis

H_0: There will be no significant difference in activation of the Core muscles between the ST exercises of upper and lower extremities.

Alternate Hypothesis

H_1: There will be significant difference in activation of the Core muscles between the ST exercises of upper and lower extremities.

REVIEW OF LITERATURE

Keywords used: Core muscles, electromyogrpahy, suspension training, TRX

Search engine used: Google scholar, Pubmed

Duration: 2 months

1. Nicola W. Mok, Ella W. Yeung, Jeran C. Cho, Samson C. Hui, Kimee C. Liu, and Coleman H. Pang

Journal of Science and Medicine in Sport, 2015

The study "Core muscle activity during suspension exercises" examines the activation levels of core muscles during four suspension workouts: hip abduction in plank, hamstring curl, chest press, and 45° row. Conducted with 18 healthy young participants, the research used surface electromyography (sEMG) to measure muscle activity normalized to each individual's maximal voluntary isometric contraction (MVIC). Results showed that the hip abduction in plank elicited the highest core muscle activation, while the 45° row had the lowest. The study found that suspension training demonstrated greater core muscle activation compared to traditional exercises on stable surfaces, highlighting its effectiveness for core stability training.[20]

2. Ronald L. Snarr, Ashleigh V. Hallmark, Brett S. Nickerson, and Michael R. Esco

Journal of Strength and Conditioning Research, 2016

The study titled "Electromyographical Comparison of Pike Variations Performed with and without Instability Devices" investigates the electromyographical (EMG) differences in muscle activation during various pike exercise variations performed on stable and unstable surfaces. Twenty physically active participants performed five variations: traditional pike (PK), BOSU ball pike (BOSU), suspension training device pike (ST), Swiss ball pike (SB), and Core Coaster pike (CC). Results showed that instability devices (BOSU, suspension training device, Swiss ball, and Core Coaster) elicited significantly higher EMG activation in the rectus abdominis, external oblique, rectus femoris, and lumbo-sacral erector spinae compared to the traditional stable pike. Notably, the suspension training device produced the highest activation in the external oblique, rectus femoris, and lumbo-sacral erector spinae. The conclusion drawn was that instability devices provide a greater challenge for core musculature, making them more effective for resistance-trained individuals, while traditional stable pikes may not adequately stimulate the core, suggesting a need for progression to instability exercises in training and rehabilitation programs.[13]

3. Giovanni Cugliari and Gennaro Boccia

Journal of Human Kinetics, 2017

The study "Core Muscle Activation in Suspension Training Exercises" examined the differences in core muscle activation across four suspension training exercises: roll-out, bodysaw, pike, and knee-tuck. Using electromyography, the researchers measured the activation of core muscles of the seventeen healthy participants, including the rectus abdominis, internal and external obliques, and paraspinal muscles. The results revealed that the roll-out produced the highest activation, reaching 140% of maximum voluntary contraction (MVC) for the lower rectus abdominis, while the bodysaw reached 100% MVC. The pike and knee-tuck exercises had lower activation levels of 57% and 54% MVC, respectively. Significant differences were noted, particularly favoring the roll-out for engaging core muscles. The findings suggest that suspension training can effectively enhance core muscle activation, providing insights in designing effective training programs.[4]

4. Sean Harris, Elise Ruffin, Wayne Brewer, and Alexis Ortiz

The International Journal of Sports Physical Therapy, 2017

The study "Muscle Activation Patterns During Suspension Training" involved 25 healthy adults (16 men and 9 women) who performed suspension training (ST) exercises, including push-ups, planks, rows, and bridges, alongside their stable surface counterparts while muscle activation was measured using surface EMG electrodes. Results showed significant increases in muscle activation for various muscle groups during ST exercises, particularly in the pectoralis major, rectus abdominis, obliques, middle trapezius, and erector spinae during push-ups and other exercises. The study concluded that suspension training enhances muscle activation compared to traditional exercises on stable surfaces, indicating its potential benefits for improving strength and stability.[19]

5. Xiujie Ma, Wei Sun, An Lu, Pei Ma, and Chuanyin Jiang

Journal of Exercise Science & Fitness, 2017

The study "The improvement of suspension training for trunk muscle power in Sanda athletes" aimed to investigate the effects of suspension training (ST) on trunk muscle power in elite Sanda athletes compared to traditional training methods (TT). Twelve athletes were randomly assigned to an experimental group (EG) that engaged in ST and a control group (CG) that followed TT for 10 weeks, training three times a week. The EG performed suspension exercises designed to enhance core muscle strength and power, while the CG engaged in traditional core strength exercises. Performance was assessed using peak torque (PT), PT/body weight (BW), and rate of force development (RFD) at different velocities. The results showed significant improvements in the EG at higher velocities, indicating that ST was more effective in enhancing explosive power of trunk muscles compared to TT. At lower velocities, the performance differences between the two groups were less pronounced. The study concluded that suspension training is a superior method for improving trunk muscle power in Sanda athletes, particularly in terms of explosive strength.[27]

6. Giuseppe Francesco Giancotti, Andrea Fusco, Alice Iannaccone and Cristina Cortis

Journal of Functional Morphology and Kinesiology, 2018

The study "Short-Term Effects of Suspension Training on Strength and Power Performances" examined the acute effects of a 50-minute Suspension Training (ST) session on 88 participants, consisting of 46 males and 42 females, which included exercises such as Suspended Plank, Sprinter’s Start Knee-Up, Chest Press, Pike, Single Leg Squat, T Deltoid Fly, Oblique Crunch, and Squat Jump, on strength and power performances, while also considering gender differences. Results indicated that male participants showed significant improvements in strength and power metrics, while female participants did not exhibit any notable changes. The findings suggest that ST is effective for enhancing strength and power in males, but the effects may differ by gender. The study concludes that while ST can be beneficial for male participants.[18]

7. David A. Krause, Joshua J. Elliott, Domenic F. Fraboni, Taylor J. McWilliams, Rachel L. Rebhan, and John H. Hollman

The International Journal of Sports Physical Therapy, 2018

The study "Electromyography of the Hip and Thigh Muscles During Two Variations of the Lunge Exercise: A Cross Sectional Study" investigated muscle recruitment differences between a standard lunge and a suspended lunge in 30 healthy participants. Using electromyography (EMG), the researchers found that the suspended lunge elicited significantly greater muscle activation in the hamstrings, gluteus medius, gluteus maximus, and adductor longus, while rectus femoris recruitment did not differ significantly between the two exercises. The results suggest that the suspended lunge is a more demanding exercise and can be considered a progression from the standard lunge, offering useful insights for clinicians in developing lower extremity exercise programs.[28]

8. Joan Aguilera-Castells, Bernat Buscà, Jose Morales et al.

PLOS ONE, 2019

The study titled "Muscle activity of Bulgarian squat. Effects of additional vibration, suspension and unstable surface" investigates how different training modalities, specifically the use of vibration plates, suspension devices, and unstable surfaces, affect muscle activation of rectus femoris, vastus medialis, vastus lateralis, biceps femoris and gluteus medius during the Bulgarian squat exercise. Conducted with twenty healthy male university students, the research aimed to assess the impact of these variations on muscle activity levels. The findings revealed that the incorporation of vibration and unstable surfaces significantly influenced muscle activation patterns, suggesting that these methods could enhance the effectiveness of strength training. The study emphasizes the potential benefits of integrating these training techniques into exercise regimens for improved performance and muscle engagement.[17]

9. Serkan Pancar, Hüseyin Topçu, Ramiz Arabacı, and Tonguç Vardar

Journal of Eurasia Sport Sciences and Medicine, 2021

The study "The Effect of TRX Suspension Training on Physical Capacity of Young Sedentaries" investigated the effects of TRX suspension training on physical performance in sedentary young men, involving 30 male participants with a mean age of 18.41 years, who were divided into a control group and a TRX training group. Over an 8-week period, the TRX group engaged in training three times a week for 45 minutes, while the control group did not participate in any physical activity. Performance tests for flexibility, strength, speed (30 m), and vertical jump were conducted before and after the training. Results showed no significant differences in speed and vertical jump between the groups, but the TRX group demonstrated significant improvements in flexibility and strength, indicating that TRX suspension training can effectively enhance these physical capacities in sedentary young men.[16]

10. Blasco, J.-M.; Dominguez-Navarro, F.; et al.

Medicina, 2024

The study "The Effects of Suspension Training on Dynamic, Static Balance, and Stability" investigated the impact of a 9-session suspension training program on balance and stability in healthy, untrained young adults. Conducted at the Universitat de València with 48 participants aged 18 to 30, the research assessed static and dynamic balance, posturography stability, and performance-based functionality. Results showed significant improvements in dynamic balance, particularly in the Y Balance Test and other performance measures, while static balance and posturography measures did not exhibit significant changes. The study concluded that suspension training is a safe and effective method for enhancing dynamic balance and functional performance.[14]

METHODOLOGY & PROCEDURE

STUDY DESIGN

A Cross sectional, within-subject design was used in an institutional laboratory equipped with surface electromyography (sEMG) and a suspension trainer anchored securely. Participants performed two ST exercises in a single session, one for the upper extremity and one for the lower extremity using the TRX Suspension Trainer Kit (Wearslim, Iorder Enterprises Private Limited, Delhi, India). The exercises included the TRX Y Fly (TYF) and the Suspended Lunge (SL) for the upper and the lower extremity respectively. The ethical committee of Abhinav Bindra Sports Medicine and Research Institute (**ABSMARI Ethics Committee**) approved the study protocol under reference number **ABS-IEC-2023-PHY-012**. Informed consent was obtained from all participants.

SAMPLE SIZE CALCULATION

The sample size calculation was performed using G*Power v.3.1.9.4. A priori power analysis for t test: "Means: Difference between two dependent means (matched pairs)" was used. Assuming a significance level (α error) of 0.05, a statistical power of 0.80 (1- β error), and an effect size (d) of 0.6, the sample size of 24 participants were obtained. To account for possible dropouts, we included 25% more participants than the number recommended by the power analysis.[28]

SUBJECTS

Thirty healthy adults, with an average age of 23.4 years ± 3.12, a height of 171.63 cm ± 8.04, and a weight of 67.33 kg ± 7.94, volunteered to join the study. Participants recruited through word of mouth, and none had prior experience with ST exercises. The study included healthy men aged 18 to 30 years who were able to complete three consecutive repetitions of the two selected exercises. Participants were excluded if they (1) had any pain, injury, or medical condition at the time; (2) were actively engaged in sports training; or (3) had recent injuries, musculoskeletal issues, or cardiovascular or respiratory diseases. They were also asked to avoid intense physical activity for 24 hours before the experimental sessions.

INSTRUMENTATIONS

The sEMG data were collected using the Pheezee® device (Startoon Labs, Hyderabad, India), a portable, battery-operated system designed for low-power use. The device comprised two modules: an upper module for managing power and a lower module featuring a custom-built EMG bioamplifier. Self-adhesive Ag/AgCl electrodes (Sunfox, Sunfox Technologies Pvt Ltd, India) were attached via a 3-lead sEMG cable, with one electrode serving as a reference and the other two capturing differential EMG signals. The recorded sEMG signal was first processed by the device's internal electronics, followed by a custom digital filtering process to remove noise, executed by an onboard microcontroller. The Root Mean Square (RMS) value of the band-pass filtered signal was then used to quantify muscle activity. The digitally filtered data was then transmitted wirelessly to the Pheezee® app running on an Android smartphone via Bluetooth.

The maximal voluntary isometric contraction (MVIC) was determined by calculating the peak of the RMS signal during an isometric test, as detailed in later sections. The primary measure of muscle activity was the RMS value, expressed as a percentage of the MVIC (%MVIC).

PROCEDURES

Prior to the test, the descriptive variables (age and dominance of lower extremity) and the anthropometric variables of the sample (height, weight and body mass index) were collected. Consistent with previous research, leg dominance was determined by asking participants which leg they would choose to kick a ball.[17,28,29]

Electrode Placement

The sEMG signals were measured from four core muscles – the rectus abdominis (RA), external oblique (EO), internal oblique (IO) and erector spinae (ES) on the dominant side of the body. Prior to electrode placement, the skin was prepared according to SENIAM guidelines,[30] with an inter-electrode distance of 20 mm.[31–33] Electrode placement followed established protocols from previous research studies.

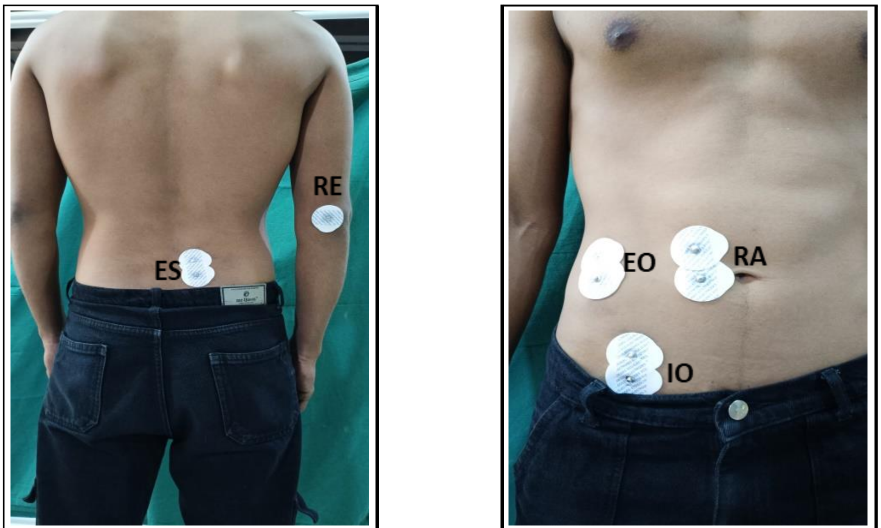
For the RA, electrodes were placed 2 cm lateral to the umbilicus.[20,34]

For the EO, electrodes were placed 14 cm lateral to the umbilicus, above the anterior superior iliac spine (ASIS).[4,35]

For the IO, the electrodes were placed 2 cm below the most prominent point of ASIS, just medial and superior to the inguinal ligament.[4,35]

For the ES, the electrodes were placed 3 cm lateral to the spine, at the level of the L3 vertebra.[33,36]

The reference electrode was placed on the right elbow.



(a) (b)

Figure 1 : Electrode plament:
(a) RE= Reference electrode, ES = Erector spinae;
(b) RA = Rectus abdominis, EO = External oblique, IO = Internal oblique

Maximum Voluntary Isometric Contraction (MVIC)

After all electrodes were placed, MVIC exercises were conducted for each muscle group, lasting 5 seconds, with a 2-minute rest between exercises to allow for normalization of the EMG data.

For the RA, the participant's body was positioned supine with hips and knees flexed at 90° and feet secured. The exercise involved a trunk flexion (crunch) movement against resistance applied at the shoulder level.[4,37]

For the EO and IO, participants were positioned on their side with their hips aligned at the edge of the bench, and their feet stabilized by a second operator. The exercise required performing a side-bend against resistance applied at shoulder level.[4,37]

As for the ES, participant lay in a prone position with the ASIS positioned at the edge of the bench, and their feet secured by a second operator. The participants performed a back extension exercise against resistance applied at shoulder level.[4,37]

(a) (b) (c)

Figure 2 : Exercises used to measure maximum voluntary isometric contraction (MVIC) of : (a) rectus abdominis; (b) external and internal oblique; (c) erector spinae

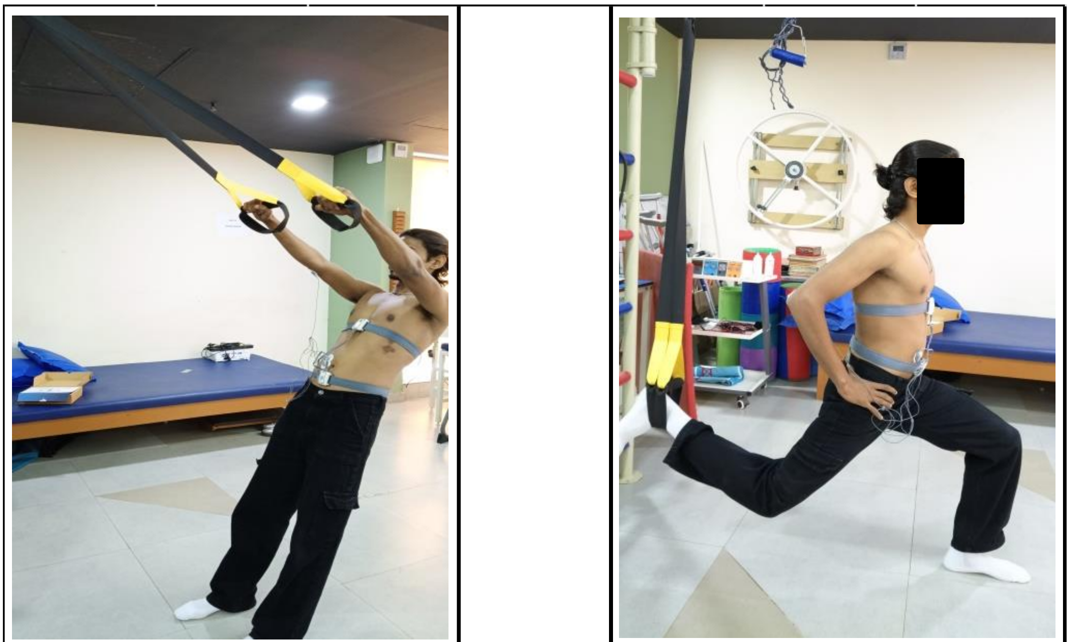
Exercise Protocol

Once the EMG data were normalized, all participants were instructed on the correct technique for each exercise. Each exercise was performed three times, with each repetition lasting 6 seconds. A metronome set to 30 beats per minute was utilized to regulate timing, dividing each repetition into four beats: 2 seconds for moving from the initial to the final position, 2 seconds for holding the final position, and 2 seconds for returning to the starting position.

A 3-minute rest period was provided between exercises to ensure complete recovery. The order of exercises was randomized for each participant.

1) *TRX Y Fly (TYF):* Participants stood upright facing the TRX anchor, with their feet shoulder-width apart and holding onto the TRX handles. They stepped forward to create a slight lean away from the suspension trainer and slowly extending their arms. From this inclined position with a straight torso, they engaged their shoulders to pull the TRX handles up over their heads, forming a "Y" shape with their bodies. They then controlled the descent of the handles back to the starting position, keeping their bodies aligned and straight throughout the movement.[16]

2) *Suspended Lunge (SL):* For the suspended lunge, participants placed the dorsum of their non-dominant foot in the suspension strap loop, which was adjusted so that the tibia was parallel to the floor. The participants performed the lunge by sliding the suspended leg and torso posteriorly while flexing the forward knee to a 90˚ angle. The trunk was kept upright, and the hands were maintained on the hips throughout the exercise.[28]



(a) (b)

Figure 3 : Suspension training exercise:
(a) TRX Y Fly; (b) Suspended Lunge

Statistical Analysis

Data analysis was performed using IBM SPSS Statistics 25 software (IBM Corp., Armonk, NY). The Shapiro-Wilk test was used to evaluate the normality of the data. To compare the differences in normalized sEMG data between two ST exercises for each muscle, a paired t-test was utilized. The level of significance was set at $p \leq 0.05$. Results are expressed as mean and standard deviation.

RESULTS

All participants completed both exercise condition and were included in the data analysis. Demographic information for the participants is presented in Table 1.

Table 1 - Demographic data of the participants (n = 30)				
	AGE (years)	**HEIGHT (cm)**	**WEIGHT (kg)**	**BMI (kg/m^2)**
MEAN	23.4	171.63	67.33	22.94
Standard Deviation	3.12	8.04	7.94	3.05

Descriptive data of the normalized sEMG activity of all the muscles are shown in Table 2. We found a significant difference in muscle activation of all the studied four muscles between the TYF and SL. The p value for the RA, EO, IO and ES between two exercises was 0.000, 0.001, 0.001 and 0.000 respectively. Similarly the effect size (d) for the RA, EO, IO and ES between two exercises was 0.9, 0.8, 0.8 and 0.9 respectively.

Table 2 - Percentage of maximum voluntary isometric contraction (MVIC %) for each muscle under two different exercises.				
Muscle	**TRX Y FLY** **MEAN ± SD**	**SUSPENDED LUNGE** **MEAN ± SD**	**P-value**	**Effect Size (d)**
RA	36.18 ± 15.07	23.88 ± 11.84	0.000	0.9
EO	38.07 ± 18.13	24.48 ± 15.51	0.001	0.8
IO	51.12 ± 15.21	67.47 ± 23.82	0.001	0.8
ES	52.24 ± 12.23	36.83 ± 18.97	0.000	0.9
RA = Rectus Abdominis; EO = External Oblique; IO = Internal Oblique; ES = Erector Spinae; SD = Standard Deviation				

During the TYF, ES (52.24 ± 12.23) showed the maximum activation, followed by IO (51.12 ± 15.21), EO (38.07 ± 18.13) and RA (36.18 ± 15.07). Similarly, IO (67.47 ± 23.82) activation was highest during the SL, followed by ES (36.83 ± 18.97), EO (24.48 ± 15.51) and RA (23.88 ± 11.84).

The differences in sEMG (MVIC %) between TYF and SL for each muscle is shown in Figure 4. When compared between the exercises, the activation of RA, EO and ES were higher during TYF, whereas IO was higher than all the three muscles during SL.

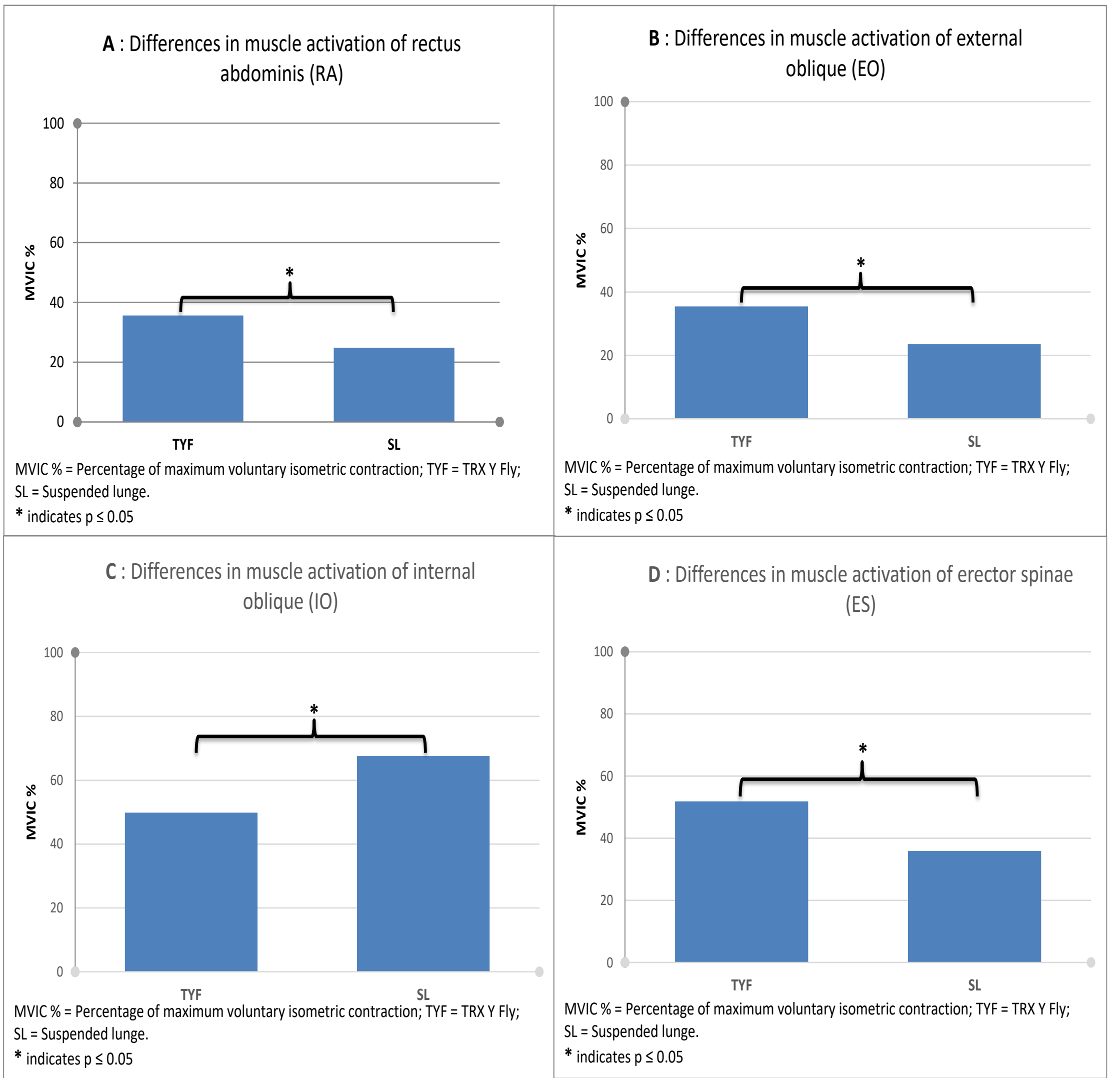


Figure 4: Differences in muscle activation between exercises.

DISCUSSION

The core musculature is vital for enabling the spine to move freely throughout its complete range of motion and serves as a functional center within the kinetic chain, facilitating the connection between the upper and lower extremities.[38] This study was aimed to investigate the difference in the activation of core muscles while performing ST exercises of the upper and lower extremities, i.e., TYF and SL respectively. The results of this study revealed significant differences in muscle activation between the exercises, with each exercise emphasizing different core muscles. These findings contribute to the growing body of research on the effects of ST on muscle activation and provide insights into the specific benefits of these exercises for core strength and stability.

To facilitate comparisons between exercises, muscle activation levels were classified into four categories based on established criteria: less than 21% was categorized as low, 21–40% as moderate, 41–60% as high, and greater than 60% as very high, in accordance to the previous research.[4,20,28,39,40] Muscle activation level of the core muscles during the TYF and the SL are shown in Table 3.

Table 3 - Level of muscle activation

	VERY HIGH (> 60 % MVIC)	**HIGH (41 - 60 % MVIC)**	**MODERATE (21 - 40 % MVIC)**	**LOW (< 21 % MVIC)**
TRX Y FLY	X	IO ES	RA EO	X
SL	IO	X	RA EO ES	X

MVIC = Maximum voluntary isometric contraction; RA = Rectus abdominis; EO = External oblique; IO = Internal oblique; ES = Erector spinae; x = nil

According to the overload principle, achieving effective strength gain typically requires muscle contractions of 60% or greater of MVIC, while activities at less than 25% of MVIC are crucial for maintaining stability.[4,40,41] While other authors[42,43] have previously reported, that to improve muscular strength, activation level greater than 40% of MVIC are required. Interestingly, Ekstrom et al., 2007, proposed that the percentage of MVIC is equivalent to the percentage of a one-repetition maximum (1RM), which represents the highest level of muscle exertion in a single repetition and suggested that exercises generating muscle activation less than 45% of MVIC are considered particularly effective for endurance and motor control training.[44] Exercises implemented in this study demonstrated moderate, high and very high muscle activation. These exercises can facilitate progression for participants or athletes within a training or rehabilitation program by promoting gradual advancements in strength and functional capacity.[45]

In this study, during the TYF exercise, the ES and IO demonstrated high activation, followed by the RA and EO with moderate activation. While a direct comparison between the selected upper extremity exercise (TYF) and those reported in previous studies cannot be made, the following differences can be highlighted. A prior study demonstrated that by adjusting the direction of movement and the lever arm of the upper limb, while ensuring the lumbar spine remained in a neutral position, RA and EO reached an activation level that facilitated improvements in muscle endurance and strength.[46] The present study revealed similar muscle activities in the RA and EO during the TYF exercise, both demonstrating moderate activation levels that are suitable for endurance training. The findings of this study showed that, the IO achieved an activation level of 51.12 % of MVIC during TYF exercise, which is higher than the 40% threshold as described by Ebert et al., 2017.[42] As a result, this exercise can be deemed effective for strength training of the IO. In a previous study, scaption and upper extremity proprioceptive neuromuscular facilitation (PNF) diagonal flexion (D1F and D2F) movements demonstrated moderate to high activation of the erector spinae (ES).[47] During the TYF exercise, which involves upper extremity movement comparable to scaption and PNF D2F, the findings of this study revealed that the ES demonstrated a high level activation, consistent with earlier findings.[47] Performing upper limb exercises in a standing position generates torque within the torso, activating abdominal and back muscles, with the ability to selectively engage core muscles by adjusting the lever arm and direction of movement.[46] Thus, the TYF exercise effectively engages the core muscles, which play a vital role in maintaining spinal stability and proper posture during dynamic upper-body movements.[5,6]

In this study, the SL exercise elicited moderate activation (21 - 40 % MVIC) in the RA, EO and ES and very high activation in the IO (more than 60 % MVIC). Previous studies have investigated the muscle activity of the hip and thigh muscles during the SL.[17,28] Krause et al. (2018) concluded that the suspended lunge demonstrated greater leg muscle activation and is a more advanced and challenging exercise compared to the standard lunge.[28] The current study found moderate muscle activation (21–40% MVIC) of the RA, EO, and ES during the SL, while other studies demonstrated low muscle activation (less than 21% MVIC) of these muscles during the traditional lunge.[44,48,49] This difference in muscle activation may be attributed to Krause et al.'s conclusion that the SL is a more demanding exercise.[28] The findings of this study revealed that the IO demonstrated very high activation during the SL, indicating its effectiveness in engaging the lateral core muscles, which play a critical role in rotational stability and control.[50] The greater activation of the IO muscle during the suspended lunge suggests that this exercise is particularly effective for improving core strength in the frontal and transverse planes. The suspended lunge, which involves stabilizing the torso during a unilateral lower-body movement, effectively engages core muscles. This finding is consistent with previous research on the enhanced activation of core muscles through unilateral exercises compared to bilateral training.[51,52]

The findings of this study revealed statistical significant difference (**p ≤ 0.05**) between TYF and SL for all the four muscles. The effect size (cohen's d) for RA, EO, IO and ES were **0.9**, **0.8**, **0.8** and **0.9**.

Core stability exercises are categorized into two main types: those designed to improve coordination and control of the trunk muscles for better lumbar spine and pelvis management, and those aimed at increasing the strength and endurance of these muscles to meet control demands.[46] The comparative analysis of muscle activation between the TYF and SL exercises highlights the specificity of ST exercises in targeting different aspects of core musculature. While the TYF primarily engages the posterior chain and central core muscles, the SL emphasizes the lateral core muscles, particularly the IO. This specificity underscores the importance of exercise selection in designing training programs aimed at improving overall core strength and stability.

PRACTICAL IMPLICATION

The results of this study offer valuable insights for both athletes and clinicians. Athletes, particularly those in sports demanding high core stability and control, may benefit from incorporating exercises like the TYF and SL into their training regimens to enhance performance and minimize injury risk. Clinicians can integrate these exercises into rehabilitation programs to target and strengthen specific core muscles according to individual patient needs.

LIMITATIONS

The small sample size, although determined through a priori power analysis, limits the generalizability of the findings.

The study assessed only immediate muscle activation during the exercises.

The sample consisted of healthy young adults, which may not represent broader populations.

FUTURE SCOPE

Future research should involve larger and more diverse populations to validate these findings.

Longitudinal studies are needed to assess the long-term effects of these exercises on core strength and stability.

Investigate how varying intensity or load during these exercises influences muscle activation patterns for a more nuanced understanding.

Multicentric study on similar technique may be encouraged for generalizability.

CONCLUSION

This study reveals that the ST exercises, including the TYF for the upper extremity and the SL for the lower extremity, produce distinct patterns of muscle activation. The TYF exercise notably activates the ES and IO muscles, while the SL exercise leads to very high activation in the IO and moderate activation in the RA, EO, and ES. These findings demonstrate that each exercise targets different core muscle groups, providing unique benefits for training and rehabilitation. The results support the use of these exercises to enhance core strength and stability.

SUMMARY

The study employed a cross-sectional, repeated measures within-subject design to evaluate muscle activation during the TYF and SL exercises. sEMG was used to detect significant differences in activation patterns between the exercises. The TYF primarily engaged the ES and IO, while the SL notably increased activation in the IO and moderately involved the RA, EO, and ES. These findings indicate that both exercises effectively target different core muscle groups, offering insights into their potential benefits for performance enhancement and rehabilitation. The results improve our understanding of how suspension training exercises impact core musculature.

DATA AVAILABILITY STATEMENT

The datasets generated and analyzed in this study are not available to the public due to privacy and confidentiality issues. However, they can be requested from the corresponding author if needed. The original data, including raw measurements and analysis files, are securely stored and accessible upon request for research and verification purposes.

KEY POINTS

TYF results in high activation of the ES and IO muscles, with moderate activation of the RA and EO.

SL leads to very high activation of the IO, and moderate activation of RA, EO, and ES.

TYF is Effective for targeting the posterior chain and central core muscles, making it suitable for enhancing overall core stability and strength.

SL is particularly effective for engaging the lateral core muscles, especially the IO, and can improve core stability and strength, which is beneficial for rehabilitation and performance enhancement.

The SL significantly increased muscle activation in the core compared to traditional lunges, indicating its effectiveness in challenging the core muscles more intensively.

The TYF demonstrated a balanced activation across multiple core muscles, making it a comprehensive exercise for core development.

STATEMENT ON CONFLICT OF INTEREST & FUNDING

The authors declare that the research was conducted with no conflict of interest. This is purely a self-funded project work carried out by me and there is no external funding sources used for this study.

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ANNEXURES

ANNEXURE - 1

CONSENT FORM

Abhinav Bindra Sports Medicine and Reasearch Institute (ABSMARI)

Study Title: THE DIFFERENCE OF CORE MUSCLE ACTIVITY PRODUCED DURING SUSPENSION TRAINING EXERCISES OF UPPER AND LOWER EXTREMITIES IN HEALTHY ADULTS: A CROSS SECTIONAL STUDY

Principal Investigator: Dawa Sherpa

Contact Information: dawas.pt@gmail.com

You are being invited to participate in a research study conducted by Mst. Dawa Sherpa under the guidance of Dr. Chinmaya Kumar Patra (PT), Principal, ABSMARI and co-guidance of Dr. Asma Parveen (PT), Assisstant Professor, ABSMARI. The purpose of this study is to investigate the difference of core muscle activity produced during the suspension training (ST) exercises of upper and lower extremities i.e., TRX Y Fly (TYF) and Suspended Lunge (SL) respectively.
Your participation in this study is entirely voluntary. You may choose not to participate or to withdraw at any time without giving any reason. If you agree to participate in this study, you will be asked to perform the two above mentioned ST exercises during which surface electromyographic readings will be obtained from the four muscles – Rectus Abdominis, External Oblique, Internal Oblique and Erector Spinae.

Your privacy is very important to us. All information collected during this study will be kept strictly confidential. The data will be stored securely and will only be accessible to the research team. Your identity will not be revealed in any reports or publications resulting from this study.
If you have any questions about this study, please feel free to contact **Dawa Sherpa** at **dawas.pt@gmail.com**. If you have any concerns about your rights as a research participant, you may contact **ABSMARI Ethics Committee** at **iec@absmari.com**.

By signing below, you indicate that you have read and understood this consent form, that you voluntarily agree to participate in this study, and that you are at least 18 years of age.

Participant's Name: ___________________________________

Participant's Signature: ______________________________

Date: ____

Researcher's Signature: ______________________________

Date: ____

ANNEXURE - 2

ABSMARI ETHICS COMMITTEE APPROVAL LETTER

ABSMARI

ABSMARI ETHICS COMMITTEE

ABHINAV BINDRA SPORTS MEDICINE AND RESEARCH INSTITUTE,
BHUBANESWAR, ODISHA

Prof. (Dr.) E. Venkata Rao
Chairperson

Mr. Chinmaya Kumar Patra
Member Secretary

Ref. No. ABSMARI/IEC/2023/053

Date: 12/08/2023

APPROVAL LETTER
APPENDIX- VIII

MEMBERS

Dr. Smaraki Mohanty, Clinician
Dr. Satyajit Mohanty, Basic Medical Scientist
Dr. Ashok Singh Chouhan Basic Medical Scientist
Mr. Shib Shankar Mohanty Legal Expert
Ms. Annie Hans, Social Scientist
Ms. Subhashree Samal, Lay Person
Mr. Deepak Ku. Pradhan, Scientific Member

IEC-SECRETARIAT

Mr. Gouranga Ku. Padhy
Mr. Susant Ku. Raychudamani

To,

Dawa Sherpa
ABSMARI
273, PAHAL, BHUBANEWAR-752101

Protocol Title: The Difference Of Core Muscle Activity Produced During Suspension Training Exercises Of Upper And Lower Extremities In Healthy Adults: A Cross Sectional Study

Protocol ID.: ABS-IEC-2023-PHY-012

Subject: Approval for the conduct of the above referenced study

Dear Mr./Mrs./Dr **Dawa Sherpa**

With reference to your Submission letter dated 12/08/2023 the ABSMARI IEC has of the Ethics reviewed and discussed your application for conduct of clinical trial on dated 12/08/2023 (Sat Day).

The following documents were reviewed and discussed

S.N.	Documents	Document (Version/Date)
1	IEC Application Form	08-08-2023
2	Informed Consent Form	08-08-2023
3	Undertaking form PI	08-08-2023
4	CRF	08-08-2023
5	COI from the Investigators	08-08-2023

The following members were present at meeting held on 12-08-2023

S.N.	Name of the Member	Designation & Qualification	Representation as per NDCT 2019	Gender (M/F)	Affiliation with the Institution (Y/N)
1	Prof. Dr. E. Venkata Rao	Professor (MBBS, MD, Dept. of Community Med.) IMS & Sum Hospital, BBSR	Chair Person	M	N
2	Dr. Satyajit Mohanty	Director-Medcare Hospital, BBSR	Basic Medical Scientist	M	N
3	Dr. Ashok Singh Chouhan	PhD, Pharmacology, Assoc. Prof. Dept. of Pharmacology, Hi-Tech Medical College & Hospital, BBSR	Basic Medical Scientist	M	N

ABSMARI ETHICS COMMITTEE
Dt.............
BHUBANESWAR

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Utkal Signature, Plot No.-273, Ground Floor, Pahal, Bhubaneswar-752101 +91-63707-03654 iec@absmari.com

ABSMARI ETHICS COMMITTEE

ABHINAV BINDRA SPORTS MEDICINE AND RESEARCH INSTITUTE, BHUBANESWAR, ODISHA

ABSMARI

Prof. (Dr.) E. Venkata Rao
Chairperson

Mr. Chinmaya Kumar Patra
Member Secretary

Ref. No. ABSMARI/IEC/2023/053

Date: 12/08/2023

S.N.	Name of the Member	Designation & Qualification	Representation as per NDCT 2019	Gender (M/F)	Affiliation with the Institution (Y/N)
4	Dr. Smaraki Mohanty	Asst. Prof-IMS & Sum Hospital/MBBS, MD (Community Med)	Clinician	F	N
5	Mr. Chinmaya Kumar Patra	Principal-ABSMARI, MPT	Member Secretary	M	Y
6	Mr. Shiba Sankar Mohanty	Junior Counsel-Lt. Ramachandra Sarangi's Chamber / BA LLB	Legal Expert	M	N
7	Ms. Annie Hans	Disability Inclusive Development Co-Ordinator in Humanity and Inclusion (India/Nepal/Srilanka). /MA in Social Work	Social Scientist	F	N
8	Ms. Subhashree Samal	Ret. Reader-Pol Sc.	Lay Person	F	N
9	Mr. Deepak Kumar Pradhan	Asst. Prof-ABSMARI, MPT	Scientific Member	M	Y

This is to confirm that only members who are independent of the Investigator and the Sponsor of the trial have voted/ provided opinion on the trial.

This Committee approves the documents and the conduct for the trial in the presented form with necessary recommendation.

The ABSMARI IEC must be informed about the progress of the study, any SAE occurring in the course of the study, any changes in the protocol and patient information/informed consent and requests to be provided a copy of the final report.

The ABSMARI IEC follows procedures that are in compliance with the requirements of ICH (International Conference on Harmonization) guidance related to GCP (Good Clinical Practice) and applicable Indian regulations.

ABSMARI ETHICS COMMITTEE BHUBANESWAR Dt.............

Yours sincerely

Mr. Chinmaya Kumar Patra
Member Secretary

ABSMARI Ethics Committee
Pahal, Bhubaneswar

Member Secretary
ABSMARI ETHICS COMMITTEE

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ANNEXURE - 3

MASTER CHART

SL No.	AGE (years)	HEIGHT(cm)	HEIGHT (m)	HEIGHT (m^2)	WEIGHT (kg)	BMI (kg/m^2)	DOMINANCE	RA MVIC (µV)	RA_TYF (µV)	MVIC %	RA_SL (µV)	MVIC %
1	26	173	1.73	2.99	73	24.41	Right	188	133	70.74468085	49	26.06382979
2	25	177	1.77	3.13	74	23.64	Right	81	10	12.34567901	1	1.234567901
3	25	166	1.66	2.76	65	23.55	Right	117	15	12.82051282	11	9.401709402
4	26	169	1.69	2.86	65	22.73	Right	117	61	52.13675214	14	11.96581197
5	20	171	1.71	2.92	63	21.58	Right	121	69	57.02479339	63	52.0661157
6	21	176	1.76	3.1	64	20.65	Right	153	41	26.79738562	43	28.10457516
7	20	181	1.81	3.28	64	19.51	Right	106	36	33.96226415	19	17.9245283
8	22	158	1.58	2.5	61	24.4	Right	122	18	14.75409836	12	9.836065574
9	26	186	1.86	3.46	67	19.36	Right	145	86	59.31034483	54	37.24137931
10	25	157	1.57	2.46	57	23.17	Right	153	46	30.06535948	69	45.09803922
11	23	170	1.7	2.89	58	20.07	Right	127	27	21.25984252	64	50.39370079
12	26	167	1.67	2.79	65	23.3	Right	148	84	56.75675676	18	12.16216216
13	22	178	1.78	3.17	76	23.97	Right	134	23	17.1641791	20	14.92537313
14	22	159	1.59	2.53	64	25.3	Right	128	56	43.75	6	4.6875
15	26	178	1.78	3.17	78	24.61	Right	142	50	35.21126761	43	30.28169014
16	26	172	1.72	2.96	71	23.99	Right	138	57	41.30434783	28	20.28985507
17	27	168	1.68	2.82	81	28.72	Right	121	42	34.7107438	29	23.96694215
18	27	178	1.78	3.17	73	23.03	Right	94	40	42.55319149	28	29.78723404
19	26	179	1.79	3.2	75	23.44	Right	127	65	51.18110236	25	19.68503937
20	27	169	1.69	2.86	65	22.73	Right	104	35	33.65384615	24	23.07692308
21	26	177	1.77	3.13	72	23	Right	123	41	33.33333333	36	29.26829268
22	25	164	1.64	2.69	67	24.91	Right	146	76	52.05479452	32	21.91780822
23	19	187	1.87	3.5	77	22	Right	122	53	43.44262295	33	27.04918033
24	19	180	1.8	3.24	61	18.83	Right	98	31	31.63265306	25	25.51020408
25	19	173	1.73	2.99	68	22.74	Right	133	55	41.35338346	41	30.82706767
26	18	174	1.74	3.03	55	18.15	Right	147	46	31.29251701	35	23.80952381
27	19	164	1.64	2.69	70	26.02	Right	128	40	31.25	29	22.65625
28	26	163	1.63	2.66	81	30.45	Right	117	45	38.46153846	22	18.8034188
29	18	176	1.76	3.1	46	14.84	Right	136	23	16.91176471	36	26.47058824
30	25	159	1.59	2.53	64	25.3	Right	141	26	18.43971631	31	21.9858156

EO MVIC (µV)	EO_TYF (µV)	MVIC %	EO_SL (µV)	MVIC %	IO MVIC (µV)	IO_TYF (µV)	MVIC %	IO_SL (µV)	MVIC %	ES MVIC (µV)	ES_TYF (µV)	MVIC %	ES_SL (µV)	MVIC %
455	119	26.15384615	39	8.571428571	280	123	43.92857143	81	28.92857143	315	120	38.0952381	132	41.9047619
126	44	34.92063492	4	3.174603175	200	26	13	79	39.5	153	86	56.20915033	93	60.78431373
173	67	38.7283237	85	49.13294798	203	53	26.10837438	195	96.0591133	186	74	39.78494624	22	11.82795699
117	14	11.96581197	21	17.94871795	194	103	53.09278351	165	85.05154639	246	81	32.92682927	71	28.86178862
200	144	72	104	52	223	185	82.95964126	213	95.51569507	107	87	81.30841121	30	28.03738318
246	25	10.16260163	67	27.23577236	342	140	40.93567251	278	81.28654971	216	134	62.03703704	106	49.07407407
320	118	36.875	19	5.9375	258	70	27.13178295	61	23.64341085	187	84	44.9197861	15	8.021390374
471	132	28.02547771	33	7.006369427	229	137	59.82532751	309	134.9344978	156	44	28.20512821	34	21.79487179
567	102	17.98941799	27	4.761904762	363	280	77.13498623	141	38.84297521	358	243	67.87709497	75	20.94972067
165	46	27.87878788	42	25.45454545	426	304	71.36150235	288	67.6056338	256	92	35.9375	146	57.03125
642	449	69.9376947	40	6.230529595	553	277	50.09041591	326	58.95117541	503	272	54.07554672	131	26.04373757
232	84	36.20689655	71	30.60344828	268	169	63.05970149	263	98.13432836	314	229	72.92993631	6	1.910828025
244	78	31.96721311	116	47.54098361	553	199	35.98553345	227	41.04882459	251	158	62.94820717	236	94.02390438
346	90	26.01156069	98	28.32369942	217	102	47.00460829	81	37.32718894	310	208	67.09677419	211	68.06451613
324	204	62.96296296	126	38.88888889	367	204	55.58583106	323	88.01089918	163	54	33.12883436	34	20.85889571
235	49	20.85106383	25	10.63829787	180	87	48.33333333	110	61.11111111	205	94	45.85365854	73	35.6097561
156	87	55.76923077	66	42.30769231	342	250	73.0994152	272	79.53216374	136	77	56.61764706	67	49.26470588
193	64	33.16062176	89	46.11398964	251	120	47.80876494	127	50.59760956	218	104	47.70642202	56	25.68807339
219	90	41.09589041	47	21.46118721	249	127	51.00401606	173	69.47791165	146	74	50.68493151	60	41.09589041
165	106	64.24242424	91	55.15151515	354	185	52.25988701	257	72.59887006	274	143	52.18978102	132	48.17518248
256	95	37.109375	57	22.265625	416	133	31.97115385	231	55.52884615	265	144	54.33962264	79	29.81132075
268	40	14.92537313	32	11.94029851	223	120	53.81165919	138	61.88340807	178	109	61.23595506	58	32.58426966
417	75	17.98561151	54	12.94964029	368	203	55.16304348	259	70.38043478	115	62	53.91304348	64	55.65217391
486	287	59.05349794	39	8.024691358	264	182	68.93939394	142	53.78787879	258	127	49.2248062	81	31.39534884
231	62	26.83982684	49	21.21212121	416	207	49.75961538	347	83.41346154	345	166	48.1159420	147	42.60869565
447	197	44.07158837	102	22.81879195	352	158	44.88636364	239	67.89772727	215	123	57.20930233	48	22.3255814
323	220	68.11145511	67	20.74303406	286	163	56.99300699	184	64.33566434	266	139	52.2556391	99	37.21804511
428	184	42.99065421	158	36.91588785	435	238	54.71264368	341	78.3908046	186	118	63.44086022	54	29.03225806
146	85	58.21917808	31	21.23287671	246	116	47.15447154	134	54.47154472	210	97	46.19047619	106	50.47619048
237	62	26.16033755	66	27.84810127	382	194	50.78534031	328	85.86387435	345	176	51.01449275	120	34.7826087