Human Biology Review (ISSN 22774424) 10(3) 2021
Human Biology Review
www.humanbiologyjournal.com
Original scientific paper (Kumar et al., 282-292)
Modified and Accepted on July 2, 2021

Upper extremity muscles interactions during Forward Walkover activity on balancing beam - an Electromyographic analysis

H. Kumar[1], A. Gulati[2], R. Jain[3] and R. Tiwari[4]

Citation: Kumar H, Gulati A, Jain R and Tiwari R. 2021. Upper extremity muscles interactions during Forward Walkover activity on balancing beam - an Electromyographic analysis. Human Biology Review, 10 (3), 282-292.

[1]Harish Kumar, Assistant Professor, Department of Sports Science, Punjabi University, Patiala. Email: <harish_ss@pbi.ac.in>
[2]Aruna Gulati, Associate Professor (Sports Sciences), Indira Gandhi Institute of Physical Education and Sports Sciences (University of Delhi), Delhi. Email: gulatiaruna@yahoo.co.in
[3]Rita Jain, Associate Professor (Sports Sciences), Indira Gandhi Institute of Physical Education and Sports Sciences (University of Delhi), Delhi. Email: everestrjain@gmail.com
[4]Rahul Tiwari, Lead Biomechanist, Sports Authority of India (SAI), Netaji Subhas National Institute of Sports (NS NIS), Patiala. Email: rahultiwari.pt@gmail.com
Corresponding author: [1]Harish Kumar, Assistant Professor, Department of Sports Science, Punjabi University, Patiala. Email: <harish_ss@pbi.ac.in>

ABSTRACT

The application of the research findings in various fields of sports sciences had paved the way to the designing of training programs for the athletes and had given heartening results by improving the performances in almost all sports events. Still certain important areas, like analysis of the muscle involvement patterns in various sports skills have not been paid due attention. Due to the complexity of the skills involved in gymnastics, it is very difficult to analyze the muscle recruitment patterns and to know about which muscle was acting at a particular instant and also to what extent. The present endeavor had been undertaken with the aim to analyze the upper extremity muscles interactions during Forward Walkover activity on balancing beam using electromyographic (EMG) techniques and kinesiological concepts. EMG has a unique contribution in revealing what a muscle actually does at any given moment even during complex and fast occurring movements. Electromyographic (EMG) activities of eight superficial muscles from the upper extremity had been analyzed using a multichannel recorder (Sensormedics, R612, Netherlands). The signal conditioning was made through a coupler (Direct/Average EMG type 9852A), preamplifier (type 820), and amplifier (type 412). The muscles Triceps brachii lateral, Deltoid anterior and Deltoid middle were observed to be the main contributory muscles during the Forward Walkover activity on balancing beam. The moderate level of activation was exhibited by Deltoid posterior and Triceps brachii long muscle. However, the activation level of Brachioradialis, Flexor carpi radialis and Biceps brachii were observed to be comparatively lower. The sequential recruitment patterns of the muscles were also discussed. The findings likely to find utility for the sports scientists and coaches in the scientific orientation of the training schedules for the gymnasts.

Keywords: Gymnastics, Muscle Recruitment, Electromyography, Forward Walkover, Balancing beam

INTRODUCTION

The performance of the athletes in sports events depends largely upon the development and learning of sports skills. Studies have shown that there is a continuous improvement in the performance of all of the sports events in the Olympic Games, which are the oldest and the biggest sports competition on the earth. The improvement in the weight lifting event (middle weight category) was observed to be as high as 97.95% from the first Olympic games held in 1896 to the year 1972 (Sachdeva, 1993; Sachdeva and Verma, 1995).

It is very important to analyze the role of major muscles required in various sports skills so that the training can be imparted to improve the efficiency of those muscles. Some attempts had been made to analyze the muscle involvement pattern in various games [Herman, 1962; Kamon and Gormley,1968; Erikson et. al., 1978; Anderson et. al.;1974; Dyhre Poulson, 1987; Anderson et. al., 1991; Goswami et. al., 1993, Nummela et. al., 1994; Mohan et. al., 1995; Koukoubis et. al., 1995; Dyson et. al., 1996; Hancock and Hawkins, 1996; Handel et. al., 1997; Rokite et. al., 1998; Bernasconi et. al., 2009; Bressel et. al., 2011; Andrzej et. al., 2019; Dimitrios et.al., 2020] However, there were very few such studies in gymnastic skills.

Both men and women compete in artistic gymnastics, but the balancing beam events are unique to female gymnasts in the Olympic Games and other international competitions. Balancing Beam, the most difficult event in women's gymnastics, requires a gymnast to be graceful, powerful, full of control, rhythmically beautiful, and also to possess flexibility and mental focus to perform various events on the balancing beam. A gymnast performs a wide array of athletic maneuvers, including rolls, walkovers, cartwheels, handspring, somersaults, back tucks etc. on balancing beam. One basic maneuver in a gymnast's balancing beam pallet is Forward Walkover, which could be seen at all levels of competitive gymnastics, from local level competitions to Olympic Games as it is a unique elemental maneuver, that draws upon a wide set of gymnastic skills.

There was an urgent need of a systematic study to analyze the role of major muscles and their interactions levels during Forward Walkover skill on balancing beam. The relative intensity and duration of muscle involvement to a specific gymnastic skill or to a set of skills would enable the sports scientists and coaches to know about the major muscles required for that skill and accordingly, the training techniques could be modified and subsequently training be imparted to develop the set of muscle groups in right proportions.

Varieties of methods are used to study the actions of muscles. But all these methods can only explain the muscle actions during simple movements. In complex actions, which involves more than one movement at different joints and where the action occurs very quickly, these methods cannot provide the real insight of what is happening with different muscles. The electromyography (EMG) studies are able to analyze the exact muscle involvement patterns even in complex and fast sports actions.

Surface Electromyography is a non-invasive technique for measuring muscle electrical activity that occurs during muscle contraction and relaxation cycles. EMG is unique in revealing what a muscle actually does at any moment during movement and dynamic postures. Moreover, it reveals objectively the fine interplay or coordination of muscles, this is impossible by any other means. (Basmajian and De Luca, 1985).

The present study was undertaken with the aim to analyze the selected eight upper extremity muscles interaction levels during Forward Walkover activity on balancing beam using electromyographic (EMG) technique and kinesiological concepts.

METHODOLOGY

The study was conducted on seven female gymnasts aged between twelve and twenty-three years to analyze the eight upper extremity muscles involvement patterns during Forward Walkover Activity on balancing beam using Electromyographic (EMG) techniques. All the subjects possessed a good degree of skill in various gymnastic activities as evidenced by their previous performances.

Selection of Muscles:

The non-invasive technique of recording muscles potential from the surface of the body was employed in the present investigation. Following eight muscles of upper extremity (from both right and left sides of the body) were selected:

Brachioradialis, Flexor Capri radials, Biceps brachii, Triceps brachii long, Triceps brachii lateral, Deltoid anterior, Deltoid middle, Deltoid posterior

Instrumentation:

Electromyographic (EMG) activities for different muscles during the activity had been obtained using a multichannel recorder (Sensormedics, R612, Netherlands). Bipolar surface electrodes were used to obtain the electrical signals from the muscles. The electrodes were silver/silver chloride type (Sensormedics, Netherland) with a contact diameter of 8 mm. The signal conditioning was made through a coupler (Direct/Average EMG type 9852A), Preamplifier (type 820) and amplifier (type 412).

Procedure:

For the placement of electrodes, the superficial muscles of the upper extremity of both sides of the body were palpated individually using their anatomical attachments and kinesiological concepts. To standardize the electrode placement position, the concept of lead line length and subsidiary line length as described by Thorstensson et al. (1982) was followed. The skin surface above the belly of the muscles was rubbed with saline water until the surface became red. The electrodes were filled with the electrode gel and placed over the center of the belly of the muscles in the anatomical axis. The electrodes were sealed in their respective positions with adhesive tape. Inter-electrode distance was kept 3 cm.

To avoid the possible pull on the electrodes during the execution of gymnastic activities, the electrode wires were looped and taped to the skin few cm away from the electrode. Reference electrodes were placed on the forehead after cleaning the surface with saline water. An adjustable elastic belt was put around the waist of the subject and the electrode wires were inserted inside the belt to avoid the pull on the electrodes and hindrances of wires during the execution of the activity.

EMG Recordings:

All the EMG activities were recorded on a continuous chart paper. EMG signals were recorded during maximum voluntary contraction (MVC) and during Forward Walkover activity on balancing beam using Multichannel Recorder (Sensor-medics R612, Netherland). The EMG's were recorded in the average mode. The mode gave the linear envelope of the average EMG signal. The signal was rectified and filtered for the range of 5.3 Hz to 1 kHz and the recording was proportional to the average number, amplitude and duration of EMG pulses (Harding and Sen, 1969). Although recording in average mode did not indicate sudden peaks of the EMG signal, nevertheless the calculations and measurements of the amplitude became easier (Dainty and Norman, 1987). The gain of amplification was selected according to the level of activity of the selected eight muscles of the upper extremity on both sides of the body. Prior to each session of recording, calibration of pen deflection of the recorder was made.

Recording of MVC:

For the recording of MVC, the subject was asked to perform the specific movements of a particular muscle against maximum resistance given by the supporter (Method described by Kendal and Kendal, 1964) and the EMG was recorded. The procedure was repeated thrice and a rest period of 2-3 minutes was given between each recording. Maximum average muscle potential developed in one second was taken as a measure of MVC. Such recordings of two or three muscles were taken per day to minimize the effect of fatigue on the subject. Chart speed was fixed at 10 mm per second for the recordings of MVC.

Recordings during Forward Walkover on the balancing beam:

For the process of execution of Forward Walkover on the balancing beam by the subjects, four phases had been marked as shown in Fig. 1. After each phase, a mark was put on the moving graph using a manual marker attached with the machine. It was done to facilitate the explanation of the results obtained and muscles interaction patterns during the execution of the activity. The machine was set at a speed of 25 mm per sec. For the EMG recording during Forward Walkover on balancing beam, a supporter was asked to handle the wires and to move with the gymnast to avoid the hindrances of wires in the execution of the activity. The timer was set at the rate of 1 sec.

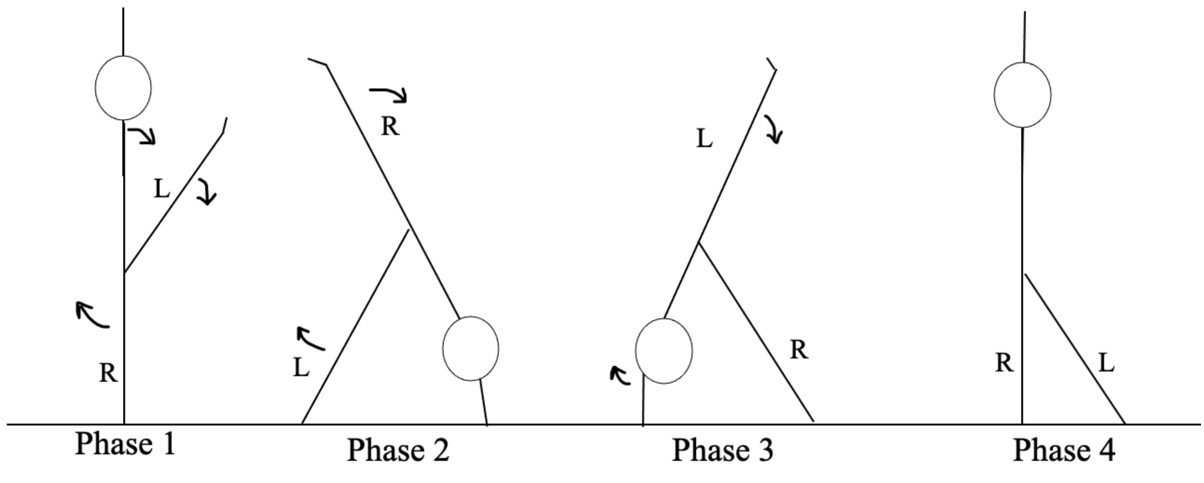

Figure 1: Various Phases of Forward Walkover (Where, R = Right, L = Left and → represents direction of the movement)

RESULTS [Table 1, Fig. 2]

The results related to the involvement of selected upper extremity muscles were expressed as the percentage of MVC. For the purpose of sequential recruitment, a muscle was considered to be active only if it exhibited an involvement of more than 20% of its MVC. A muscle showing an involvement of more than 40% of its MVC was considered as highly active (main contributory muscle) and that between 20% and 40% of its MVC was said to be moderately active whereas, a muscle exhibiting an activation level of less than 20% of MVC was considered as slightly less active.

Out of the eight muscles studied, the contribution of the five muscles namely Triceps brachii lateral, Deltoid middle, Deltoid anterior, Triceps brachii long and Deltoid posterior from upper extremity were noticed to be high. Whereas the remaining three muscles namely Flexor carpi radialis, Brachioradialis and Biceps Brachii exhibited low to moderate participation during the Forward Walkover activity on balancing beam.

Sequential Recruitment of the muscles of upper extremity:
The two muscles, namely, Deltoid anterior (right and left) and Deltoid middle (right and left) from the upper extremity sprang into action during the transitional phase 1-2 of Forward Walkover Activity on balancing beam followed by four more muscles, namely, Brachioradialis (right), Triceps brachii long (right), Triceps brachii lateral (right and left) and Deltoid posterior (right) during the next phase i.e. phase 2 of the activity. The five muscles, namely, Brachioradialis (left), Flexor carpi radialis (right and left), Biceps Brachii (right and left), Triceps brachii1ong (left) and Deltoid posterior (left) from the upper extremity started their activities during the transitional phase 2-3 of the Forward Walkover activity on balancing beam.

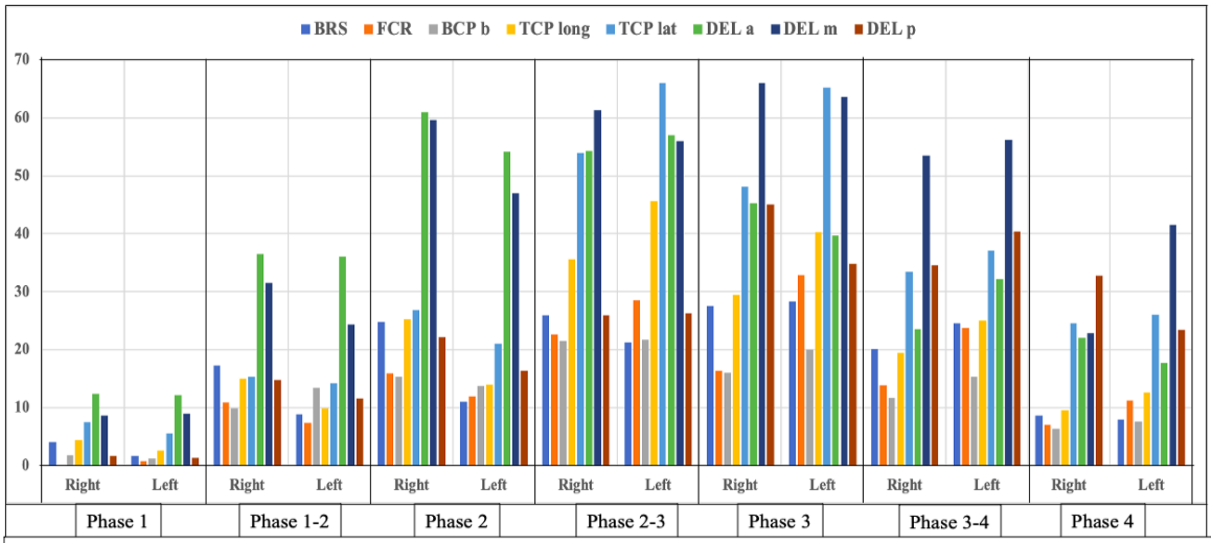

Figure 2: Magnitude of activation & recruitment pattern of upper extremity muscles during various phases of Forward Walkover on Balancing Beam (Where, BRS=Brachioradialis, FCR=Flexor carpi radialis, BCP b=Biceps brachii, TCP long=Long head of Triceps brachii, TCP lat=lateral head of Triceps brachii, DEL a=Deltoid anterior, DEL m=Deltoid middle, DEL p=Deltoid posterior)

Magnitude of upper extremity muscles involvement during various phases of Forward Walkover activity on balancing beam

Phase 1

At the starting position, that is, phase 1 of the Forward Walkover activity on balancing beam, the muscle Flexor carpi radialis did not show any activity at all. From amongst the selected muscles of upper extremity, the maximum levels of involvement of 12.42% for the right side and 12.16% for the left side of the body was shown by Deltoid anterior muscle. Activities of Triceps brachii lateral (right) and Deltoid middle (right and left) were observed to range between 5% and 10%. Rest of the muscles included in the study showed the involvement levels of less than 5% of their MVC values at this phase.

Phase 1-2

The activities of all the muscles under study depicted an increasing trend during transitional phase 1-2 as compared to phase 1 of the FWO activity on balancing beam. Percent involvements of Deltoid anterior and Deltoid middle muscles were of the order of 36.47% and 31.51% respectively on the right side of the body, and 36.10% and 24.36% respectively on the left side of the body. The muscles Brachioradialis (left), Flexor carpi radialis (left) and Biceps Brachii (right) showed their levels of involvement of less than 10%. However, the involvements of rest of the selected muscles of upper extremity were found to range between 10% and 20% of their MVCs. The activities of all the muscles except Deltoid anterior and Biceps brachii were observed to be more on the right side than the on the left of the body.

Phase 2

All the muscles included in this study were further found to have increased levels of their respective activities at phase 2 as compared to transitional phase 1-2 of the Forward Walkover activity on the balancing beam. The maximum involvement level during this phase was found in case of Deltoid anterior (61.05% for the right side and 54.91% for the left side), followed by Deltoid middle (59.68% and 46.97% for the right and left side respectively). Involvements of other four muscles namely, Brachioradialis (right), Triceps brachii long (right), Triceps brachii lateral and Deltoid posterior (right) ranged between 20% and 40%, and the activity levels of the rest of the chosen muscles were noticed to be less than 20% of their MVCs with minimum involvement of 10.97% in case of Brachioradialis (left) muscle. The involvements of all the muscles of upper extremity were found to be more on the right side than the left.

Phase 2-3

Degrees of involvements of all the muscles included in the present study were found to exceed 20% of their MVCs during transitional phase 2-3 of Forward Walkover on balancing beam. Activity levels of all the muscles of upper extremity except Deltoid anterior (right) were observed to be higher during this phase as compared to phase 2. The four out of eight selected muscles, namely, Triceps brachii long, Triceps brachii lateral, Deltoid anterior and Deltoid middle demonstrated the activation exceeding 40% of their MVCs with maximum degree of involvement of 65.95% in case of Triceps brachii lateral (left) muscle. Involvements of rest of the muscles of upper extremity ranged between 20% and 40%. Corresponding activities of the muscles of trunk and upper extremity except Brachioradialis, Deltoid middle and Deltoid posterior were found to be greater on the left side than on the right side of the body.

Phase 3

The activation levels of Brachioradialis (right and left), Flexor carpi radialis (left), Deltoid middle (right and left) and Deltoid posterior (right and left) muscles were found to be greater at phase 3 as compared to transitional phase 2-3, whereas that of Flexor carpi radialis (right), Biceps Brachii (right and left), Triceps brachii long (right and left), Triceps brachii lateral (right and left) and Deltoid anterior (right and left) showed decreased involvement levels during this phase. The maximum involvement of the order of 66.03% for right side and 63.66% for left was shown by Deltoid middle muscle. Involvements of Triceps brachii lateral (right and left), Deltoid anterior (right), Deltoid middle (right and left), Triceps brachii long(left), and Deltoid posterior (right) were found to be more than 40% of their respective MVCs, and that of Flexor carpi radialis (right) and Biceps Brachii (right and left) were noticed to be less than 20% of their respective MVCs. Rest of the muscles included in the study showed an involvement ranging between 20% and 40% of their MVCs. Activities of Deltoid anterior, Deltoid middle and Deltoid posterior, muscles were observed to be more on the right side, whereas other muscles were involved more on the left side during this phase of the Forward Walkover activity on balancing beam.

Phase 3 - 4

Percent involvements of all the muscles included in the study, except Deltoid posterior (left), were observed to decrease during this phase of Forward Walkover activity on balancing beam, as compared to phase 3. Deltoid middle muscles showed its maximum involvement of 53.45% from right side and 56.20% from left side of the body. Involvement levels of three selected muscles, namely, Flexor carpi radialis (right), Biceps Brachii (right and left) and Triceps brachii long (right) were found to be less than 20%, with minimum involvement of 11.66% shown by Biceps brachii right muscle. However, the involvements of rest of the muscles included here ranged between 20% and 40% of their respective MVCs. All the muscles of upper extremity exhibited a greater degree of activation levels on left side than the right side of the body.

Phase 4

During phase 4, the involvements of all the muscles included in the study were observed to decrease as compared to transitional phase 3-4 of Forward Walkover activity on balancing beam. The maximum involvement level of 41.47% was shown by Deltoid middle (left) muscle. The chosen four upper extremity muscles, namely, Triceps brachii lateral (right and left), Deltoid anterior (right), Deltoid middle (right) and Deltoid posterior (right and left) showed their involvements between the range of 20% and 40% of their respective MVCs. Involvement levels of rest of the muscles were found to be of the order of less than 20%, with minimum value of 6.32% in case of Biceps Brachii (right). Five out of eight selected muscles were found to be more active on the left side than on the right except for Brachioradialis, Deltoid anterior and Deltoid posterior muscles.

Table 1: Mean and Standard Deviation (SD) values of level of activation of upper extremity muscles studied expressed as percentage of their respective MVC values during various phases of Forward Walkover activity on balancing beam.

Muscles		Percent involvement during various phases of Forward Walkover activity on Balancing Beam.													
		Phase 1		Phase-1-2		Phase 2		Phase 2-3		Phase 3		Phase 3-4		Phase 4	
		Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left
BRS	Mean	4.08	1.63	17.26	8.87	24.84	10.97	25.93	21.29	27.51	28.36	20.14	24.52	8.58	7.95
	SD	5.15	2.15	12.94	6.41	20.10	6.65	18.53	13.91	21.89	19.63	16.64	13.38	8.16	4.28
FCR	Mean	0	0.81	10.95	7.40	15.87	11.95	22.61	28.58	16.39	32.88	13.88	23.75	7.00	11.20
	SD	0	1.99	6.20	5.95	9.32	6.83	8.06	13.37	13.96	23.60	13.41	15.80	3.85	6.56
BCP b	Mean	1.75	1.27	9.85	13.41	15.34	13.69	21.50	21.71	16.07	20.01	11.66	15.32	6.32	7.59
	SD	1.22	1.20	8.04	13.65	17.47	12.85	12.14	12.50	6.06	13.24	4.22	9.59	2.00	4.18
TCP long	Mean	4.39	2.55	14.97	9.92	25.24	13.95	35.61	45.65	29.45	40.30	19.38	25.06	9.55	12.65
	SD	2.86	2.30	11.43	6.38	24.45	7.78	15.46	17.39	12.82	26.13	6.69	14.99	3.31	7.94
TCP lat	Mean	7.50	5.55	15.34	14.17	26.87	21.03	53.98	65.95	48.10	65.23	33.43	37.06	24.60	26.02
	SD	4.48	4.62	9.56	6.48	23.02	10.27	15.25	19.89	10.25	26.46	11.01	21.46	15.70	26.56
DEL a	Mean	12.42	12.16	36.47	36.10	61.05	54.19	54.25	57.04	45.23	39.74	23.52	32.13	22.10	17.75
	SD	6.62	7.92	16.97	17.80	28.37	32.56	8.63	17.30	19.16	21.38	13.15	16.33	13.51	9.12
DEL m	Mean	8.58	9.00	31.51	24.36	59.68	46.97	61.31	55.95	66.03	63.66	53.45	56.20	22.82	41.47
	SD	3.07	5.13	14.48	8.57	29.28	18.27	21.52	13.49	36.52	30.33	19.38	28.69	15.95	23.57
DEL p	Mean	1.64	1.36	14.74	11.59	22.20	16.34	25.90	26.26	45.00	34.77	34.63	40.35	32.72	23.45
	SD	2.42	2.12	11.21	5.93	22.24	9.93	20.33	17.55	28.19	24.32	19.76	26.68	27.19	10.12

DISCUSSION

During forward walkover activity on narrow balancing beam, the legs of the gymnast fully rotated in such a manner that the gymnast both started and finished in a standing upright position. Activation levels of all the selected eight muscles of upper extremity included in the present study depicted an increasing trend from the starting position (Phase 1) till transitional Phase 2-3 of the activity. The Triceps and Deltoid group of muscles were observed to be the main contributory muscles (showed the involvement of more than 60% of their respective MVCs) during Forward Walkover activity on balancing beam.

The muscle Deltoid anterior exhibited the maximum activation during Phase 2 and transitional Phase 2-3, when the gymnast held the balancing beam with her hands and body weight was borne majorly by shoulder joints, while simultaneously maintaining flexion of arms at shoulder joint and extension of forearm at elbow joint. Deltoid anterior being the prime mover in the flexion of arms at shoulder joint, also assisted in weight bearing feature of the shoulder joint. Andrzej et al. (2019) also identified Anterior Deltoid muscle from the upper extremity to improve handstand performance on parallel bars and still rings in both adult and young gymnasts.

On the other hand, the maximum involvement of Deltoid middle muscle was observed at Phase 3 during Forward Walkover Activity on balancing beam, when the right leg touched the balancing beam; and the body weight started shifting from the arms to the right leg. This muscle played a major role by facilitating the subject to attain the dynamic posture while maintaining the balance and equilibrium on the narrow balancing beam during the ongoing process of weight shifting. The only muscle, namely, Triceps brachii lateral that was noticed to be the most active during transitional Phase 2-3 followed by Phase 3, was probably to keep the elbows extended in the dynamic posture, and simultaneously maintaining balance thereby supporting the body weight bearing role by upper extremity as a whole.

Two upper extremity muscles, namely, Deltoid posterior and Triceps brachii long were also found to be highly active (between 40% and 60% of their respective MVCs) during the Forward Walkover activity on balancing beam. These muscles exhibited their maximum contributions during transitional phases 2-3 as well as phase 3. As the body weight fell on the hands during these phases, the contributing muscles sprang into action so as to keep the elbows extended alongside maintaining body weight on shoulders and arms flexed at the shoulder joints to allow the subject to change its position from phase 2 to phase 3. The activation levels of Biceps brachii, Flexor carpi radialis and Brachioradialis were found to less than 40% of their respective MVCs.

The present EMG study revealed the diminishing levels of muscle activation of the selected muscles of upper extremity region during the progression of the activity from the phase 3 to the last phase i.e. phase 4 of the Forward Walkover, which indicated the shifting of body weight back from hands to both the legs. The decrease in the activity of the Deltoid group of muscles during these phases in the present study was in sync with the results of Foidart-Dessalle et al. (2005).

The findings of the study likely to find utility in the scientific orientation of the training schedules for the gymnasts. A strong interaction between the gymnast's coaches and the sports scientists can pave the way for more fruitful individualized training schedules.

REFERENCES:

1. Anderson, JG; Jonsson, B and Ortengren, R (1974). Myoelectric activity in individual lumber erector spinae muscles in sitting; a study with surface and wire electrodes. *Scand J. rehabil Med*. 3:91-108.

2. Anderson, PA; Hobart DJ and Danoff, JV (1991). *Electromyographic Kinesiology*. Elsevier Science Publishers B.V.

3. Andrzej, K; Bartłomiej, N; Jan, M; Michel, M; Kazimierz K and Mariusz Z (2019). Changes in the muscle activity of Gymnasts during a Handstand on various apparatus. *Journal of Strength and Conditioning Research*. 33(6): 1609–1618.

4. Basmajian, JV and De Luca, CJ (1985). *Muscles Alive-Their function revealed by Electromyography. 5th ed*, Williams and Wilkins, Baltimore.

5. Bernasconi, SM; Tordi, NR; Parratte, BM; and Rouillon, JDR (2009). Can shoulder muscle coordination during the support scale at ring height be replicated during training exercises in gymnastics? *Journal of Strength and Conditioning Research*, 23 (8): 2381-2388.

6. Bressel, E; Dolny, DG; and Gibbons, M (2011). Trunk muscle activity during exercises performed on land and in water. *Med Sci Sports Exerc*. 43(10): 1927-1932.

7. Dainty, DA, and Norman, RW (1987). *Standardizing biomechanical testing in sport*. Champaign, [Ill], Human Kinetics Publishers.

8. Dimitrios, CM; Theophanis, AS; Kosmas, IC and Dimitrios, AP (2020). Construct validity of gymnastics-specific assessment on the neuromuscular function of shoulder flexor and extensor muscles. *Sports Biomech*. 7:1-16. doi: 10.1080/14763141.2020.1772861. Online ahead of print.

9. Dyhre-Poulsen, PO (1987). An analysis of splits leaps and gymnastic skill by physiological recordings. *Eur. J. Appl. Physiol*. 56: 390-397.

10. Dyson, RJ; Buchanan, M; Farrington, TA and Hurrion, PD (1996) Electromyographic activity during windsurfing on water. *J. Sports Sci.* 14(2): 125-130.

11. Erikson, A; Forsbey, A, Nerlson, J and Karlson, J (1978). *Muscle strength, EMG activity and oxygen uptake during downhill skiing-Biomechanics,* IV.B. University Park Press, Baltimore: 54-61.

12. Foidart-Dessalle, M; Krier, P; De Pasqua, V and Crielaard, JM (2005). Cinematic and electromyographic analysis of a basic athletic test: The walkover in well trained and beginners young female gymnasts. *Computer methods in Biomechanics and biomedical engineering.* 8: 101-103.

13. Goswami, A; Gupta, S; Mukhopadhyay, S and Mathur, DN (1993) An analysis of Upper body muscle involvement in overhead Forehand clear and Smash (Abstract). *1st World Congress on Science and Racket sports*. July 10-13, Liverpool, England.

14. Hancock, RE and Hawkins, RJ (1996). Applications of Electromyography in the throwing shoulder. *Clin. Orthop.* 330: 84-97.

15. Handel, M; Horstmann, T; Dickhuth, HH and Qulch, RW (1997). Effects of contract-relax stretching training on muscle performance in athletes. *Eur. J. Appl. Physiol.* 76(5): 400-408.

16. Harding, RH and Sen, RN (1969). A new simple method of quantifying the Electromyogram to evaluate total muscular activity. *J. Physiol*. 204: 66-68.

17. Herman, GW (1962) An electromyographic study of selected muscles involved in the shotput. *Res. Quart*. 33: 1-9.

18. Kamon, E and Gormley, J (1968). Muscular activity pattern for skilled performance and during learning of a horizontal bar exercise. *Ergonomics*. 11: 345-357.

19. Kendall, HO and Kendall, FP (1964). *Muscle testing and function*. Williams and Wilkins Co., Baltimore, USA.

20. Koukoubis, TD; Cooper LW; Glisson, RR; Seaber, AV and Feagin, JAJ (1995) An electromyographic study of arm muscles during climbing. *Knee Surg. Sports Traumatol Arthrose.* 3(2): 121-124.

21. Mohan, NC; Goswami, A; Fortgalland, GD and Tandon, DK (1995) Specific role of Deltoid muscle in Olympic lifts - an EMG study. *NIS Scientific Journal*. 18: 22-29.

22. Nummela, A; Rusko, H and Mero. A (1994). EMG activities and ground reaction forces during fatigued and non-fatigued sprinting. *Med. Sci. Sports. Exer*. 26(5): 605 - 609.

23. Rokite, AS; Jobe, FW; Pink, MM; Perry, J and Brault, J (1998). Electromyographic analysis of shoulder function during the volleyball serve and spike. *J. Shoulder Elbow. Surg.* 7(3): 256 - 263.

24. Sachdeva, A (1993). A comparison of best performances of athletes in various Olympic and Asian games - A physiological analysis. *Unpublished M. Sc. Dissertation,* Punjabi University, Patiala.

25. Sachdeva, A and Verma, SK (1995). Physiological analysis of Asian and Olympic swimming performances. *Ind. J. Sports Sc. Phys. Edu*. 7 (2): 41-57.

26. Thorstensson, ALF; Carlson, H; Zomlefer, MR; & Nilsson, J (1982). Lumbar back muscle activity in relation to trunk movements during locomotion in man. *Acta Physiologica Scandinavica*. 116: 13-20.