Muscle Fatigue as a Measure of Work Stress in Tractor Operation

[1]Vidhu K. P, [2]Tewari V. K.
[1]Vignan's University, Department of Mechanical Engineering, Vadlamudi, Guntur
[2]Indian Institute of Technology, Agricultural & Food Engineering Department, Kharagpur

ABSTRACT

Tractor driving is more strenuous than any other vehicle operation, where, nearly half the energy of the driver is spent in bracing himself against the seat and damping out jerks. This, along with the extreme conditions of temperature, humidity and solar radiation, impose tremendous stress on the operator's health and working efficiency. An insight into the muscle fatigue of the operator can be gained through study of electrical activity of the concerned muscles. This muscle fatigue study could be used as an indicator to assess the stress level of the operator. Considering the movement in the hand-arm and whole body system in tractor operation, four muscles of hand-arm viz., flexi carpi radialis (FCR), extensor digitorum (ED), brachio-radialis (BR) and middle deltoid (MD) and four body muscles on the right side of trunk, viz., trapezius- superior region (UT), trapezius- intermediate region (MT), latissimus dorsi (LD) and erector spinae (ES) were selected for the current study. The average value of muscle load in terms of reference voluntary electrical (RVE) activity was observed to be the highest in FCR (15.14%) and the lowest in BR (4.44%) in transportation operation. The frequent turning of the trunk during field operation have resulted in higher load on UT muscle. A decrease of the median power frequency (MPF) of all the muscles with time was observed, which indicates muscle fatigue during tractor operation. The study indicated that work stress assessment in tractor operation could be done through muscle fatigue analysis, which needs to be reduced by suitable interventions.

Key words : Muscle fatigue, work stress, Reference voluntary electrical activity, median power frequency

INTRODUCTION

Tractors have become the most important power source in the modern Indian agriculture. They are used for primary tillage, secondary tillage and transportation of goods including human and animals in addition to other industrial uses. The Indian tractor market has traditionally been a medium horse power market, with 31–40 hp tractors accounting for 42.3% of the total industry volumes during 2010-11, but the trend is slowly shifting towards higher horse power tractors (ICRA, 2011). Moreover, the scarcity of labour in the agricultural sector has almost ensured that any farming work cannot be completed without the use of mechanical power, if the timeliness in operations and the increased production targets are to be maintained. While driving the tractor, the operator frequently uses various controls such as gear shifting lever, accelerator, hydraulic lever etc along with controlling the steering. Most of the operators use their dominant hand-arm system for actuating the controls. These operations require fingers flexion and extension. The vibration energy transmitted to and absorbed by the hand arm and whole body system results in relative compression and extension of muscle tissues (Reynolds, 1977). Therefore, an insight into the muscle fatigue of the operator can be gained through study of electrical activity of the concerned muscles.

Fatigue is felt while performing a work or an exercise, more specifically for that with prolonged efforts. There are two types of physical fatigue, which are whole body or localized. The term of "localized muscle fatigue (LMF)" was introduced by Chaffin (1973), as a decrement in muscle generating capacity. Fatigue is a gradual process, while the endurance is associated with a capability limit to maintain a certain effort. Biomechanically, the existence of fatigue can be predicted by capacity declines in certain muscles. Physiologically, fatigue is also associated with increases in heart rate, body temperature, and oxygen uptake. It has been reported that high levels of musculoskeletal discomfort and/or cumulative discomfort arising through localized fatigue among symptom-free workers may develop into musculoskeletal pain in the long term (Reenen et al, 2008).

MATERIALS AND METHODS

The frequent lifting and lowering the implement to adjust the depth of operation and control of various levers require fingers flexion and extension in tractor driving. Along with the finger, wrist also gets flexion and extension movement. Simultaneously, hand is used to grip the steering of the tractor. The grip force is increased due to vibration in the handle. Upper arm is flexed during shifting of gear changing lever. The upper arm is also flexed when using the hydraulic lever for lifting the implement during turn. During all the field operations, it is regular practice of the operator that he controls the steering with left hand and use the levers with right hand. Therefore, right hand muscles were taken for measurement of fatigue. In the movement in the hand-arm system, four muscles viz., flexi carpi radialis (FCR), extensor digitorum (ED), brachio-radialis (BR) and middle deltoid (MD) could be considered as prominent in action. FCR is a powerful muscle for flexion of wrist. It abducts hand and acts as a synergist of elbow flexion. ED is antagonist of flexure muscle. It is a prime mover of finger extension. It is responsible for wrist extension and can abduct fingers. BR is synergist in forearm flexion. During rapid flexion and extension, it acts to prevent joint separation. Deltoid is prime mover of arm abduction. If only anterior fibers are active, it can act powerfully in flexion and medial rotation of humerus. It affects extension and lateral rotation of arm. Considering the movement in the hand-arm system, four muscles of hand-arm were identified for the present investigation as flexi carpi radialis (FCR), extensor digitorum (ED), brachio-radialis (BR) and middle deltoid (MD) (Hoozemans and Dieen, 2005).

The erect sitting posture over a highly vibrating platform enhances the contraction of back muscles for longer durations. The tractor operator has to frequently turn back and see the working of implement during field operations. The usual practice followed by tractor operators is to turn through his right side for this. Vibration and posture induced low back pain, which is prevalent in tractor drivers could be attributed to the flexion-relaxation phenomenon (FRP) of back muscles. Tight latissimus dorsi has been shown to be one cause of chronic shoulder pain and chronic back pain. Because the latissimus dorsi connects the spine to the humerus, tightness in this muscle can manifest as either sub-optimal glenohumeral joint (shoulder) function which leads to chronic pain or tendinitis in the tendinous fasciae connecting the latissimus dorsi to the thoracic and lumbar spine (Paul et al., 2009). Hence four body muscles on the right side of trunk, viz., trapezius- superior region (UT), trapezius- intermediate region (MT), latissimus dorsi (LD) and erector spinae (ES) were selected for the current study. Considering the fact that tractor is widely used for transportation also in our country, along with primary farming operations viz., first till with mb plough, second till with disc harrow and puddling with rotavator, transportation with load also was selected for the study. Twelve experienced tractor drivers participated in the experiments who were detailed the requirements of the study to avail full co-operation.

Subjects performed maximum voluntary contraction (MVC) to obtain reference voluntary electrical activity (RVE) of the selected muscles. Three separate activities for hand muscles and another four activities for body muscles were performed to fully load the muscles. To record the EMG signal, a standard procedure was followed.

The raw EMG signals during work were normalized. The signals were first band passed filtered with low frequency of 10 Hz and then high frequency of 400 Hz. The median frequency and rms amplitude of the muscles were determined through software (BTS Bioengineering, Italy). The RVE of the each muscle was then calculated. The rms amplitude of EMG signal was calculated for every operation of each subject in both the selected conditions. 3

RESULTS AND DISCUSSIONS

The RVE values of selected hand and body muscles are presented in Table 1 and 2 respectively. It is apparent from the Table that the maximum RVE was recorded for the BR muscle (0.3497 mV). Corresponding effort at MVC was recorded as 38±5.61 kg. It was followed by RVE of MD (0.1893 mV), ED (0.1378 mV) and FCR (0.1294 mV). Further, highest RVE was recorded for LD muscle (0.3813 mV) at 14.5±1.83 followed by ES (0.3278 mV), UT (0.25 mV) and MT (0.2383 mV) in case of body muscles.

Table 1 : RVE of hand muscles for selected subjects

Subject	Amplitude (rms) of muscles response at MVC, mV				Effort at MVC, kg		
	FCR	ED	BR	MD	FCR and ED	BR	MD
1	0.1123	0.0728	0.3241	0.1327	32	43	24
2	0.1476	0.1328	0.4835	0.2874	37	52	26
3	0.1235	0.1785	0.2861	0.1867	30	34	25
4	0.0589	0.2089	0.3313	0.1867	37	37	27
5	0.0613	0.1668	0.4105	0.2486	29	35	25
6	0.1145	0.1415	0.3143	0.1912	39	40	28
7	0.1988	0.1105	0.3326	0.0875	27	37	27
8	0.1789	0.1904	0.3767	0.2473	30	34	27
9	0.1985	0.0951	0.2474	0.1887	40	40	32
10	0.1695	0.2088	0.2765	0.1256	33	39	29
11	0.1178	0.0976	0.3213	0.1543	26	30	28
12	0.0707	0.0498	0.4926	0.2352	41	35	22
Average	0.1294	0.1378	0.3497	0.1893	33.42	38.00	26.67
SD	0.0502	0.0536	0.0774	0.0584	5.21	5.61	2.57

The Electromyography record for all the operators in all selected operations with selected 8 muscles was taken for a period of continuous 15 min of operation. The plot of averaged EMG activity of all selected subjects in hand and body muscles during transportation is presented in Fig 1 and 2 respectively. It may be mentioned here that the subjects are taken as replications in the current study.

Table 2 : RVE of body muscles for selected subjects

Subject	Amplitude (rms) of muscles response at MVC, mV				Effort at MVC, kg			
	UT	MT	LD	ES	UT	MT	LD	ES
1	0.1965	0.1101	0.5218	0.2267	45	35	15	22
2	0.3058	0.2380	0.3470	0.4587	42	36	12	24
3	0.2109	0.3049	0.4967	0.3006	49	34	16	25
4	0.2340	0.3363	0.2719	0.3502	39	35	14	26
5	0.2387	0.3129	0.3407	0.4316	38	38	12	24
6	0.2148	0.2456	0.2832	0.3266	42	37	15	21
7	0.3451	0.1887	0.2974	0.1593	45	39	18	26
8	0.3056	0.3332	0.3634	0.4120	47	40	12	28
9	0.3613	0.1970	0.4503	0.2853	39	41	14	29
10	0.2824	0.3566	0.4606	0.2251	38	42	15	24
11	0.1781	0.1558	0.2823	0.2700	41	42	16	25
12	0.1267	0.0802	0.4607	0.4873	40	43	15	26
Average	0.2500	0.2383	0.3813	0.3278	42.08	38.50	14.50	25.00
SD	0.0707	0.0930	0.0914	0.1027	3.65	3.12	1.83	2.26

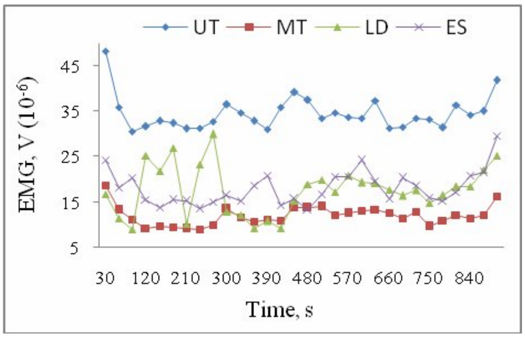

Fig 1: Average EMG activity of hand muscles body muscle during transportation

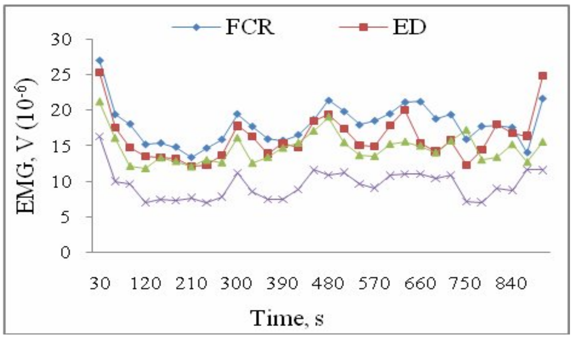

Fig 2: Average EMG activity of body muscle during transportation

The average EMG signal recorded during transportation for the FCR was found to be ranging from 13.33 to 27.06 µV while for the ED, it ranged between 12.1 to 25.2 µV. The trend of all hand muscles were almost the same but MD showed a lower range between 6.99 to 16.2 µV. The fact that there is less lifting action performed during the transportation could have been the reason for low EMG activity for the MD muscle. In case of body muscles, the maximum activity was seen in UT muscle in the range of 30.5 to 48.3 µV. The range of LD muscle was lower, but showed some abrupt changes in between. The MT and ES muscles almost showed similar trend during transportation.

The trend in EMG activity during first till showed similar trend for all the hand muscles except a few places. The range for FCR was highest at 16.6 to 36.5 μV, whereas ED, BR and MD showed similar results. In body muscles, UT was much active ranging between 14.2 to 46.4 μV while LD, MT and ES were almost comparable. The ES had a lower range at the starting but gradually increased till approximately 10 min of trial and then declined.

In case of second till operation, FCR and ED were at similar trend ranging between 18.4 to 39 μV, while MD showed lesser range at 10.2 to 18.5 μV. The fact that frequency of lifting the implement was comparatively lesser with respect to first till resulted in lesser EMG activity for the MD muscle. In case of body muscles, LD showed a much higher activity than first till resulting in the range of 15 to 35 μV, but UT had the highest range of 25 to 44 μV. The EMG activity in ES muscle was almost constant nature with comparative lower range than other body muscles.

As observed in other field operations, in puddling with rotavator, FCR ranged high (13.1 29.0 μV) among the hand muscles. Lowest activity was seen in MD muscle ranging between 4.3 to 16.9 μV. The BR muscle had a declination at the beginning of activity but gradually increased towards the end to finally reduce. Almost a similar trend was seen in ED muscle also. Variation in EMG activity of ES and LD were at a wider range during puddling. The MT showed a constant activity ranging between 6.2 to 14.1 μV. The UT muscle had higher range (15.6 to 30.5 μV) as seen in other cases. During puddling, operator frequently turned and checked the working of implement along with lifting the implement using levers which might have resulted higher activity in FCR and UT muscles.

The percentage load of selected hand muscles was calculated against the MVC for each muscle to assess the muscle load in different selected operations. The load on hand muscles during different operations is given in Fig 3. The response of EMG during field operation of tractor indicated an average high load on FCR muscle, followed by ED, MD and BR muscles. The average muscle load for the FCR, ED, MD and BR muscles were 15.14, 12.42, 4.95 and 4.44% RVE respectively during transportation. Their corresponding values during first till were 22.05, 17.78, 7.57 and 5.47% RVE, while during second till, it were 20.75, 21.09, 7.8 and 7.04% RVE. Puddling recorded average muscle load on hand as 18.83, 14.99, 3.97 and 4.53 for FCR, ED, MD and BR muscles respectively.

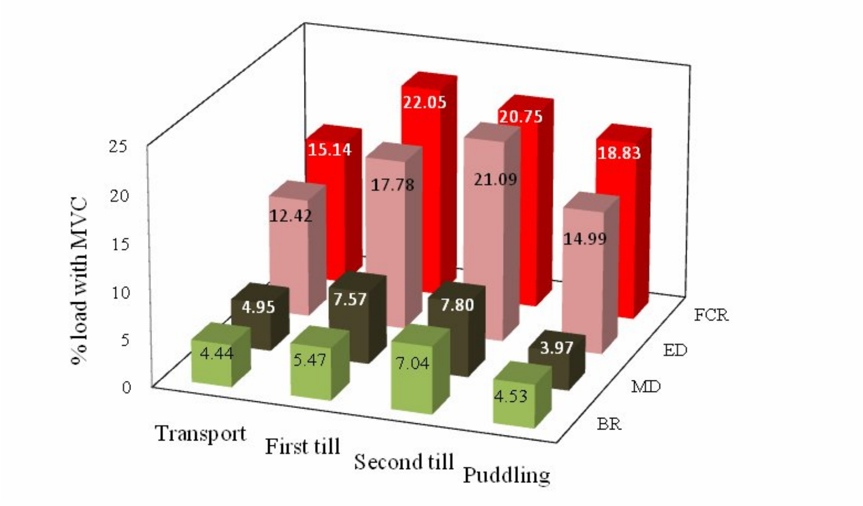

Fig 3: Load on hand muscles during selected operations

The muscle loads in selected body muscles also were calculated against MVC and presented in Fig 4. For the body muscles in selected operations, the load on UT was ranging between 10.02 to 14.54% RVE. First till and second till showed higher muscle load on MT while for the transportation and puddling it were minimal. Load on ES muscle was higher during first till (7.08%) followed by transportation (5.96%), puddling (5.72%) and second till (4.69%). Muscle load on LD muscle was higher in second till while for all other operations it was almost the same.

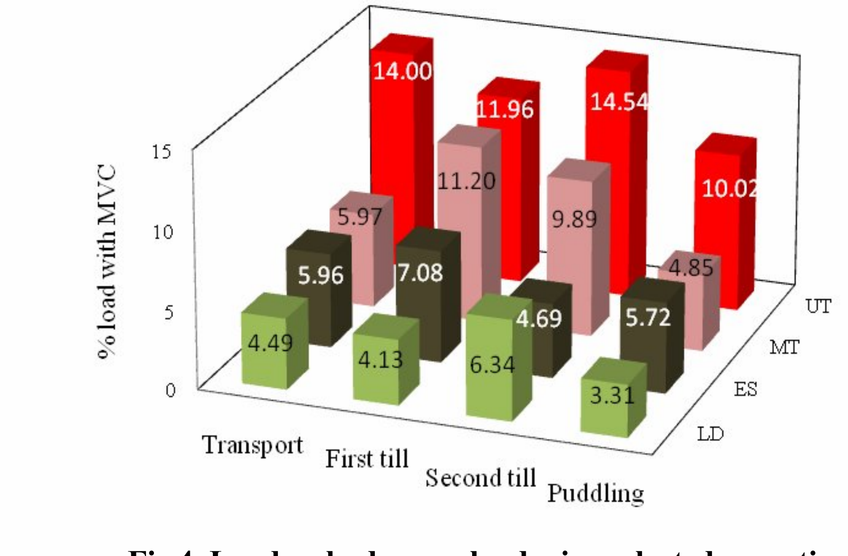

Fig 4: Load on body muscles during selected operations

The shoulder abduction was minimal during transportation and puddling which resulted in lesser load to the MD muscles. The lowest load of BR muscle during transportation was due lesser frequency of use of control levers. Field operations require grasping the steering firmly along with usage of levers which results in higher muscle load on FCR, followed by ED, MD and BR. Though the puddling operation is more strenuous which requires frequent usage of levers in lifting and lowering the implement, the load in BR and MD muscles were lowest among the selected operations. Since the unevenness of the ground coupled with the emanating vibration makes the operator to take support of the steering more in puddling which might be the cause of lower load on BR and MD muscles. The actuation of hydraulic lever intermittently for adjusting the depth as well as taking turn requires higher effort on FCR and ED muscles. Moreover, size of the field also affects the variation in muscle fatigue. Nag and Chatterjee (1981) have suggested that 20 to 30% MVC could be considered as an acceptable range of constant loading in agricultural work.

The Median Power Frequency (MPF) for all selected muscles was analyzed for selected operations. The response of MPF for the hand and body muscles during transportation is shown in Fig. 5. A decrease of the MPF of all the muscles with time was observed. The average MPF showed negative correlation with time. Its slope was equal to 0.042, 0.026, 0.013 and 0.02 Hz/s with a lesser coefficient of determination of 0.7, 0.5, 0.2 and 0.4 for FCR, ED, BR and MD muscles respectively.

In body muscle also, the decreasing trend of MPF for all muscles was observed indicating fatigue. The negative correlation was found to be with slope equating to 0.017, 0.015, 0.005, 0.014 Hz/s for UT, MT, LD and ES muscles respectively.

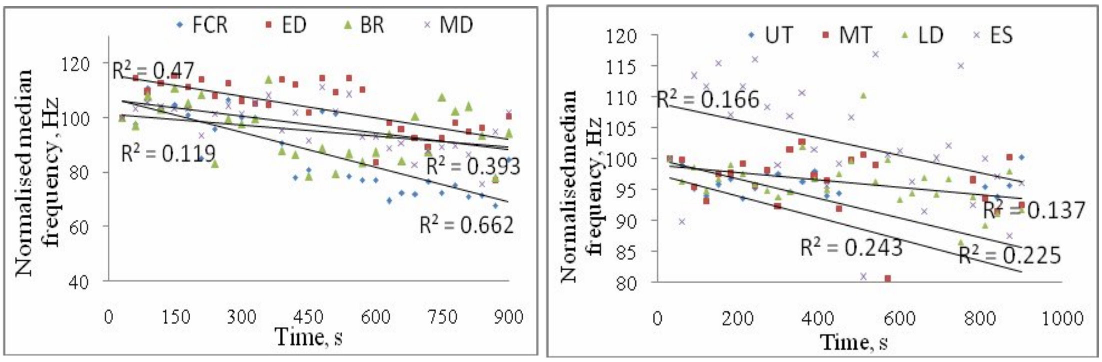

Fig 5: Effect of normalized median frequency with time for hand and body muscles during transportation

The decrease of the MPF shows the development of the fatigue process, and the fall rate can be related to the rate of the muscular decreasing force (Mello et al., 2007). It clarifies the fact that transportation operation is sufficient to induce localized muscle fatigue in most of the subjects. The localized fatigue may be due to lactic acid accumulation and a consequent pH reduction

(McArdle et al., 2001). Also, the rate of change of MPF indicates the rate of fatigue (Lariviere et al, 2004). It indicates that out of the four hand muscles, FCR fatigued more rapidly than other muscles.

Variation among the subjects in EMG activation level was considerably high in most of the cases highlighting differences in the observed frequency levels. The large variation in the MPF might be due to the fact that load of muscles were occurred during activation of the control levers which accounts for a small amount of time as compared to total duration of work. When the muscles are not active during the operation, it got relaxed and hence MPF increased. Further, vibration may be a major difficulty in obtaining workable EMG signals. Vibration has been identified as one of the major limitation in recording EMG signals in previous studies (Seroussi et al., 1989). The intra subject variability in MPF during short cycle of operation has been reported by earlier researchers also (Garg et al., 2006).

The MPF response of hand and body muscles during all selected operations is presented in Fig 6 (a) to (h). Similar trend in MPF response was observed in first till, second till and puddling operations. Average slope of the response trend was seen to be around 0.02 Hz/s for the hand muscles while for the body muscles, it was 0.03 Hz/s.

CONCLUSIONS

EMG of four hand muscles namely, flexi carpi radialis (FCR), extensor digitorum (ED), brachio-radialis (BR) and middle deltoid (MD) and four body muscles, namely, trapezius- superior region (UT), trapezius- intermediate region (MT), latissimus dorsi (LD) and erector spinae (ES) were recorded following standard procedures while operating the tractor in different farming operations. The average value of muscle load in terms of reference voluntary electrical (RVE) activity was observed to be the highest in FCR (15.14%) and the lowest in BR (4.44%) in transportation operation. The higher gripping force exerted by the subjects on the steering wheel along with frequent usage of lever controls in maneuvering the vehicle (while driving) might have caused higher load on FCR muscle. The frequent turning of the trunk during field operation might have resulted in higher load on UT muscle. A decrease of the median power frequency (MPF) of all the muscles with time was observed, which indicates muscle fatigue during tractor operation. The study indicated that work stress assessment in tractor operation could be done through muscle fatigue analysis, which needs to be reduced by suitable interventions.

STATEMENT OF RELEVANCE

The measure of the hand and body muscle activities involved in various actions performed during the different field operations of tractor-implement system in terms of reference voluntary electrical (RVE) activity would lead to systematically understanding the muscle fatigue level leading to operator's work stress. The study provided data related to fatigue level, which could be used to quantify the work stress during various farming operations with tractor.

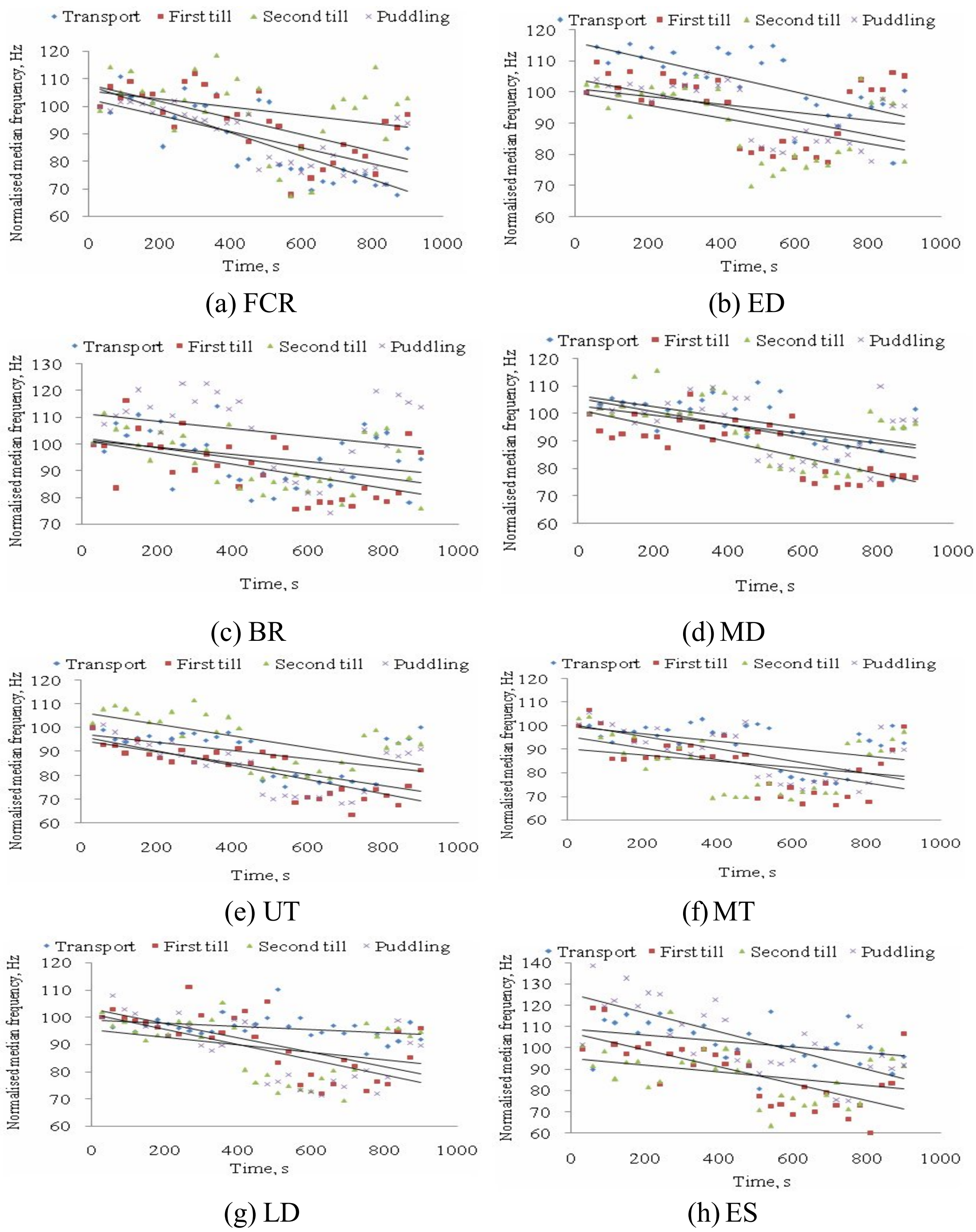

Fig 6: Effect of normalized median frequency with time for different muscles during selected operations

ACKNOWLEDGEMENT

The authors are grateful to Indian Council of Agricultural Research (ICAR) who financed for the study at IIT, Kharagpur.

REFERENCES

1. Chaffin, D.B. 1973. Localized muscle fatigue: definition and measurement. *Journal of Occupational Medicine*, **15(4)**:346-354.
2. Garg, A., Hegmann, K., and Kapellusch, J. 2006. Short-cycle overhead work and shoulder girdle muscle fatigue. *International Journal of Industrial Ergonomics*, **36**: 581-597
3. Hoozemans, M.J.M., and Dieen, J.H. 2005. Prediction of handgrip forces using surface EMG of forearm muscles. *Journal of Electromyography and Kinesiology*, **15**:358-366.
4. ICRA Report. 2011. Tractor industry: robust rural liquidity and good monsoons support demand, http://www.icra.in/files/ticker/tractor-note-march%202011.pdf, accessed on 15th May 2011.
5. McArdle, W.D., Katch, F.I., and Katch, V.L. 1991. Exercise physiology. Energy, nutrition and human performance. Third edition. Printed in USA.
6. Mello, R.G.T., Oliveira, L.F., and Nadal, B. 2007. Anticipation mechanism in body sways control and effect of muscle fatigue. *Journal of Electromyography and Kinesiology*, doi:10.1016/j.jelekin.2006.08.011.
7. Reenen, H.H., Hamberg-van, Beek, A. J. van der, Birgitte, M. Blattera, Grinten, M. P. van der, Mechelen, W. van, and Bongers, P. M. 2008. Does musculoskeletal discomfort at work predict future musculoskeletal pain, *Ergonomics,* **51 (5)**:637–648.
8. Reynolds, D.D. 1977. Hand-arm vibration: a review of three years research, In: Wasserman, D.E., Taylor, W., Curry, M.G. (Eds), Proceedings of the International Occupational Hand-Arm Vibration Conference. *NIOSH*-pub No. 77-170, 99-128.
9. Seroussi, R., Wilder, D., and Pope, M. 1989. Trunk muscle electromyography and whole body vibration. *Journal of Biomechanics*, **22**:219–229.