Available online at www.sciencedirect.com

ScienceDirect

journal homepage: http://www.elsevier.com/locate/poamed

Original research article

A survey on the actuating force on brake and clutch pedal controls in agricultural tractor in use in Iran

Nima Jamshidi [a,*], *Sayed Mohamad Abdollahi* [b], *Ali Maleki* [c]

[a] *Department of Biomedical Engineering, Faculty of Engineering, University of Isfahan, Iran*
[b] *Department of Mechanical Engineering of Biosystems, Shahrekord University, Iran*
[c] *Scientific Board in Department of Mechanical Engineering of Biosystems, Shahrekord University, Iran*

ARTICLE INFO

Article history:
Received 1 April 2015
Received in revised form
21 October 2015
Accepted 24 January 2016
Available online 28 February 2016

Keywords:
Ergonomics
Knee
Tractor
Pedal

ABSTRACT

Introduction: The focus of farm tractor operator is on forward and reverse hydraulic arm's movements in addition to leg-pushing on brake and clutch pedals. Performing all these, with respect to the machine model and operator's position, determines the posture and the loading pattern of the operator's body.

Aim: The objective here has been the assessment of the pedal control to improve the operator's functionality.

Material and methods: In this study, 1500 operators were subject to close interviews by the researcher for 3 years in Isfahan Province. Operators with different anthropometries were involved by sitting on MF285, U650, JD3140 and JD950 combiner seats. The operator's knees were photographed in: free (no force enforcement), ready (beginning of force enforcement) and active (force enforcing) conditions. The thigh and leg angle at the knee joint was measured and the exerted force on the leg during leg-pushing was calculated too.

Results and discussion: Analysis of the obtained data indicated that the MF285 tractor clutch exerted less maximum force on the knee due to the clutch mechanism. The JD3140 clutch needed more maximum force in relation to MF285. The least maximum force was exerted on the brake pedal of JD3140. Under operating conditions, the widest knee extension angle in leg-pushing was of the U650 and JD3140 tractors.

Conclusions: The U650 and JD3140 model tractors under 'ready' and 'active' conditions need less leg-pushing force. This force exertion from the knee occurs at the widest extension angle. These two models have higher ergonomic level with the least possible disturbance in the knee joint.

* *Correspondence to*: Unit 218, Department of Biomedical Engineering, Faculty of Engineering, University of Isfahan, HezarJerib St., Isfahan 81746-73441, Iran. Tel.: +98 311 7935613; fax: +98 311 6276652.
E-mail addresses: nima_jamshidi@yahoo.com, n.jamshidi@eng.ui.ac.ir (N. Jamshidi).

http://dx.doi.org/10.1016/j.poamed.2016.01.007

1. Introduction

Farm tractor operation includes movements and body segment turns and stretching which can generate discomfort in different parts of the operator's body. Some of the model tractors considered for the investigation in this paper were those sold in the developed countries some years ago and, in some cases, they are still used. Massey Ferguson and John Deerre are global companies, selling the same basic concept of an 80–100 horse power (hp) tractor in India for $150/hp, China for $250/hp, and Europe and North America for $1400/hp. The remarkable difference is mainly due to the increasing complexity in safety, comfort and environmental technical solutions adopted.[1] In the developing countries, the tractors used are not designed[1] based on ergonomics, leading to neck and shoulder, arm and leg and knee discomforts.[2–9] These mentioned models are not designed based on considering Iranian human factors and the they have been introduced to the Iranian market without any changes since long time ago.

Through interviews conducted by phone in New York State regarding skeleton-muscular pains, it has been revealed that there exists a statistically significant difference in developing skeleton-muscular pains between the farmers operating tractors and those who do not. The investigation has revealed that joint trouble includes: lower back – 41%, neck/shoulders – 35%, knees – 29%, hands/wrists – 28%, and hips – 15% ($P < 0.05$).[10]

Different designs showing where the control arms and proper calculation of forces need to operate controls on farm tractors are of major concern in operator's comfort.[11] Irrational factors such as the panel structure design, paints and design of protective equipment lead to an increase in the costs instead of safety concerns in agricultural equipment.[12,13]

The semi-automatic or full automatic electronic transmission systems could have a positive effect on ergonomic factor while increasing efficiency in farm machinery.[14] The ergonomic principles have a direct effect on the time when the operator senses fatigue.[15] Tractor ergonomics is studied through model simulation at the control arms setup. Several researches have used factor analysis in optimizing the necessary dimensions in tractor and combine in order to achieve better ergonomics.[4–7,16–19]

Widana evaluated the effect of operators work load on generating pain in different parts of the body after fatigue, working hours and reduction in motivation to work and accordingly, introduced a new farm tractor design.[20] Chaturvedi et al.[21] studied the operators physiologic and postures during the transformed vibration in addition to the material from which the seat was made.[21] Zatsirosky solved the clutch leg-pushing model by introducing two closed-loops for seat design based on the operator body segments, seat installation angles and proper diameters.[22]

The knee joint is the mostly applied body member subject to different fluctuating forces when exerting pressure on the control pedals. In this study, the knee joint has been examined during leg-pushing in agricultural machinery.

Since Iran is a developing country, there is the need for developing machinery and agricultural tractors and matching them with Iranian operators' anthropometric characteristics based on the findings of research. This study could be a new step in the design and modification of the existing tractors.

2. Aim

The objective here has been the assessment of the pedal control to improve the operator's functionality. Definitely, using the seats with specific height and anthropometric characteristics in accordance with Iranian operators can play an effective role in reducing the amount of force exerted on the knee of these people. Correcting seat height in tractors and combines, i.e., increasing the height of the seats available in Iran, can be one of the most effective strategies to improve the current situation.

Other measures that could be based on the findings of this study include adding clutch and brake force amplifier (booster) to the existing power transmission mechanism of tractors and combines. The lack of information on Iranians farm population encouraged the current researchers to quantify Iranian data. It should be noted that there are already other useful studies on other populations, but the Iranian society has been somehow neglected.

3. Material and methods

The advances made in farm tractors manufacturing industry are more concerned with the properly facilitated operating cabin. This can be observed in farming industry of Iran, where Fergusson, Romany and John Deere tractors are used.

In this study, 1500 operators were subject to close interviews by the researcher for three years in Isfahan Province, where 50 were selected for first stage experimental examinations. Then, in the second stage of supplementary experimental test, 4 out of 1500 were selected to be representative of 95% of the Iranian farm population.

Among these members of the statistical population, 4 expert operators (N_1, N_2, N_3, N_4) with very close operational backgrounds and different anthropometry and body mass indexes (BMI) were selected as the subjects of the uniform test candidates. The body descriptions are given in Table 1. To estimate the segmental body mass, the model by Lehto and Buck was employed and for body segment length, the model developed by Shan and Bohen was used.[23,24]

By evaluating the four tractor brands mentioned earlier, the ones with similar test parameters and the average life span and mechanically good condition were selected as the

Table 1 – The selected operators' physical description.

Operator	N_1	N_2	N_3	N_4
Weight, kg	72	84	83	78
Height, m	1.65	1.75	1.80	1.85
BMI, kg/m^2	26.45	27.43	25.62	22.79
Thigh length, m	0.40	0.43	0.44	0.45
Thigh weight, kg	7.32	8.71	8.60	8.02
Leg length, m	0.41	0.43	0.44	0.46
Leg weight, kg	3.08	3.53	3.49	3.31
Trunk weight, kg	0.97	1.05	1.04	1.01

Table 2 – Description of the tractors/combine considered for the investigation.

	John Deere 950	John Deere 3140	Massey Ferguson 285	Tractor U650
Engine				
Ignition system	Direct injection	Direct injection	Direct injection	Direct injection
Number of cylinders	6	6	4	4
Working cycle	4	4	4	4
Compression ratio	16:1	16:1	16:1	16:1
Nominal speed, rpm	–	2400	1750	1800
Torque at nominal speed, hp	90	90	75	65
Others				
Clutch	One plate	One plate	Two plate	One plate
Gear box	Synchromesh	Sliding mesh	Synchromesh	Sliding mesh
Forward speed (stage)	4	8	8	10
Reverse speed (stage)	1	4	2	2
Steering	Hydraulic	Hydraulic	Hydraulic	Semi-hydraulic
Front wheel drive, cm	220	150–180	150–180	150–180
Rear wheel drive, cm	170	160–180	160–180	160–180
Life cycle, years	10	13	13	15

representative test material. In the investigations on the tractor condition based on their mechanical records, it was found that most of them had worked for more than 13 years. Each operator was set in the four given tractors' seats for leg-pushing with respect to 'free,' 'ready' and 'active' conditions, beginning with a 90° flection towards more extension. These three conditions were filmed at the knee joint. The description of the tractors/combine considered for the investigation can be seen in Table 2.

In the 'free' condition, the knee was relaxed, showing no action; at the 'ready' condition, the foot was put on the pedal with no force exerted, that is, zero tension; and in the 'active' condition, the clutch pedal was fully pushed, that is, clutch engagement. By evaluating the photos, the knee angle was measured and recorded through protractor apparatus. The anti-force exerted by the pedal was measured too. The angle of leg-pushing depends on the position of the driver on the seat and the adjustment of the seat. Seats generally have vertical and longitudinal adjustment. In this research, we asked the operators to adjust their seats based on self-selected position.

Table 3 – Maximum force exerted on the operators' foot at 'active' condition.

Tractor type	Maximum anti-force by clutch pedal, N	Maximum anti-force by brake pedal, N
JD3140	266.10	372.53
MF285	253.33	710.77
U650	341.51	683.30
JD950 combine	404.30	635.85

Apart from the vibration forces exerted by the machine, the anti-force exerted by the pedal fluctuated as the three conditions were changed, that is, from zero at 'free' to the maximum force at 'active' conditions (Table 3). The force was recorded with tractor standing still and cold and the force required to act controls was higher than that of hot system.

The anti-force exerted by the pedal was measured by load cell. The load cell accuracy was 6: 0.5% of reading down to 1/50 of load cell capacity. The load cell resolution was: 1/100 000 (1/300 000*) of load cell capacity (in tension and compression). Load cell was designed based on ISO 7500, EN 10002.2, DIN 51221, ASTM E-4 standards.

With respect to the model presented by Zatsirosky[20] regarding brake and clutch pedals evaluation, the findings on these four tractors corresponded to those of both experiments. Combine and tractors are very different machines, especially for transmission, engine power, and driving station. Usually, they are not dealt together.

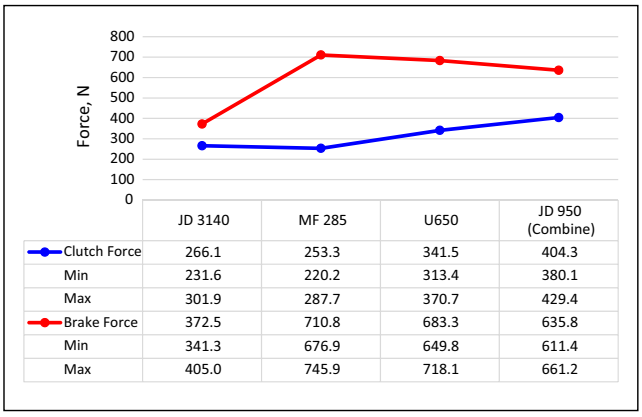
The obtained data were arranged at the ANOVA analytic tests and fed into SAS software for analysis (see results in Table 4). For each tractor model, the three conditions were analyzed through separate tests. The collected sample was 108 samples: 4 machines × 2 pedals (brake and clutch) × 4 operators (person) × 3 positions (free, ready and active).

4. Results and discussion

The obtained results indicated that in tractor type modeling there was a statistically significant probability at 5% level between the angle conditions and the anthropometric of the

Table 4 – The ANOVA test analytical results.

Source	Degrees of freedom	ANOVAs sum of squares	Mean square	F-value	Pr > F
Equipment	3	3905.61458	1301.87153	6.83	0.0003
Pedal	1	463.76042	463.76042	2.43	0.1224
Angle	2	19 485.08333	9742.54167	51.13	<0.0001
Person	3	6483.61458	2161.20486	11.34	<0.0001
Model	9	30 338.07292	3370.89699	17.69	<0.0001
Error	86	16 385.41667	190.52810	–	–



	JD 3140	MF 285	U650	JD 950 (Combine)
Clutch Force	266.1	253.3	341.5	404.3
Min	231.6	220.2	313.4	380.1
Max	301.9	287.7	370.7	429.4
Brake Force	372.5	710.8	683.3	635.8
Min	341.3	676.9	649.8	611.4
Max	405.0	745.9	718.1	661.2

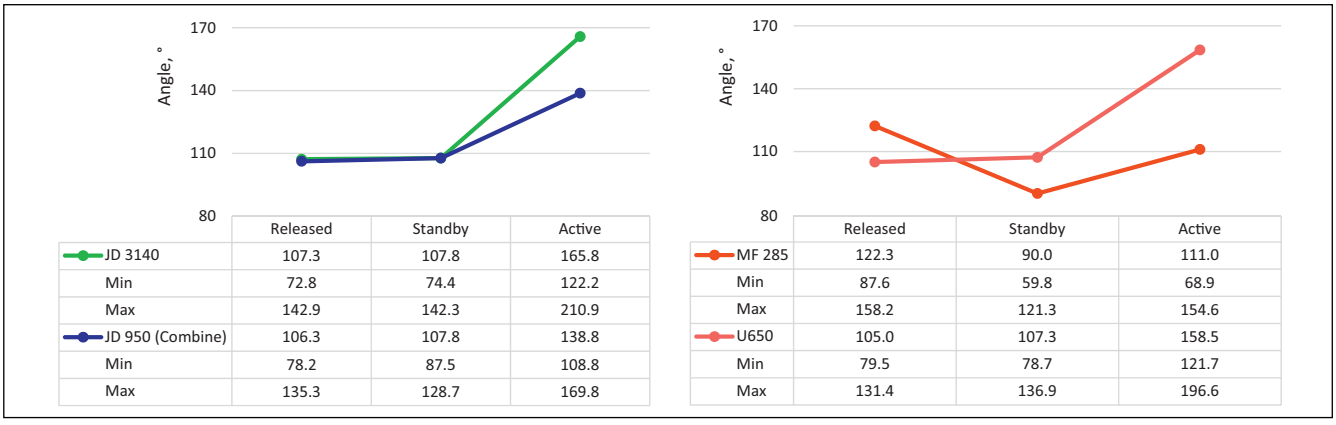
Fig. 1 – The maximum anti-force (N) exerted by the pedals.

operators. Comparing clutch and brake pedals of different tractor models did not, however, show any statistical significance.

The least maximum force inflicted by the clutch pedal was recorded in MF295 tractor, which was followed by JD3140 with a difference of 10 N, ranking the second. The least maximum force inflicted on the brake pedal was recorded in JD3140 (Fig. 1). In farm machinery, due to low speed and the frequent stop and go nature of the work, clutching occurred more than braking.

The analysis conducted on the variables in the 'free' condition indicated no significant difference in the pedals. In 'ready' and 'active' conditions, there was a significant difference at 5% level between the clutch pedals. It was also observed that the knee angle differed in the 'active' condition of different tractors. The analysis conducted on the internal forces under external loading at small opening angles and the statistical analysis indicated that when no external forces were inflicted on the foot at bigger angles as the knee was extended, less force was inflicted through the quadriceps muscle; thus, the muscular was in a better condition with less fatigue. From the 'ready' to the 'active' state, the more the opening angle and the knee extensions in force, the less the disturbance potential.

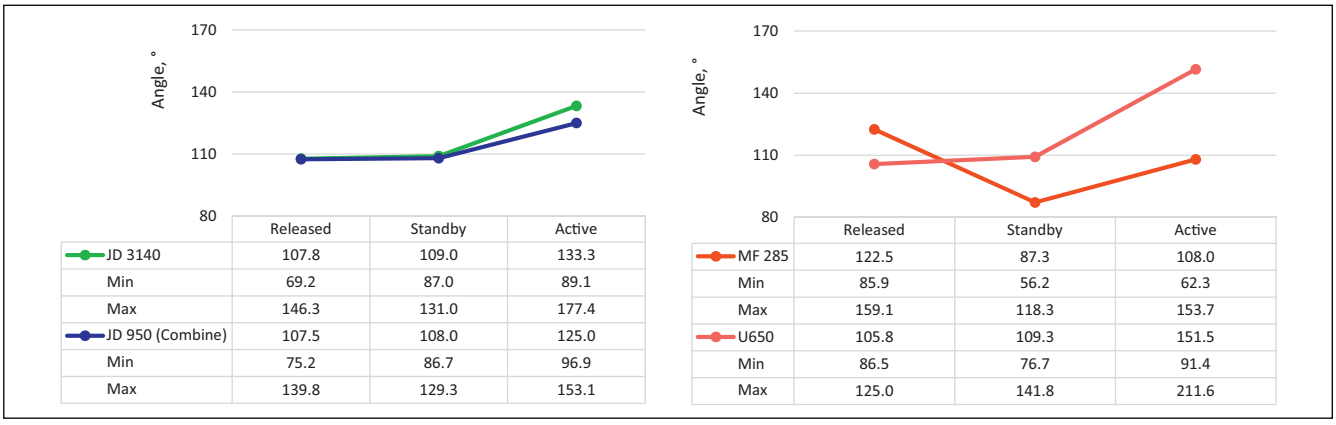
The most knee joint extension angle in the active mode occurred in leg-pushing in JD3140 and U650 tractors. The JD950 combine had the lowest standard deviation (SD). The least angle of knee joint extension in the clutch and brake occurred in leg-pushing in MF285 tractor with the highest SD (Figs. 2 and 3). The maximum anti-force exerted by



	Released	Standby	Active
JD 3140	107.3	107.8	165.8
Min	72.8	74.4	122.2
Max	142.9	142.3	210.9
JD 950 (Combine)	106.3	107.8	138.8
Min	78.2	87.5	108.8
Max	135.3	128.7	169.8

	Released	Standby	Active
MF 285	122.3	90.0	111.0
Min	87.6	59.8	68.9
Max	158.2	121.3	154.6
U650	105.0	107.3	158.5
Min	79.5	78.7	121.7
Max	131.4	136.9	196.6

Fig. 2 – The average angle of three conditions in JD3140 and JD950 (combine), and in MF285 and U650 – the clutch.



	Released	Standby	Active
JD 3140	107.8	109.0	133.3
Min	69.2	87.0	89.1
Max	146.3	131.0	177.4
JD 950 (Combine)	107.5	108.0	125.0
Min	75.2	86.7	96.9
Max	139.8	129.3	153.1

	Released	Standby	Active
MF 285	122.5	87.3	108.0
Min	85.9	56.2	62.3
Max	159.1	118.3	153.7
U650	105.8	109.3	151.5
Min	86.5	76.7	91.4
Max	125.0	141.8	211.6

Fig. 3 – The average angle of three conditions in JD3140 and JD950 (combine), and in MF285 and U650 – the brake.

the pedals was in JD3140 and U650 tractors, with the full extension of the knee joint, while the quadriceps muscle contraction was full.

5. Conclusions

The results obtained by testing the three conditions on JD3140 and U650 tractors regarding muscular disturbance indicated more safety for the operator. The least diversion was with JD950, where, in relation to different anthropometrics, there were less sensitivity and exposed similar angles in the knee joint. The lowest knee joint average observed in MF285 at the maximum force was inflicted on the pedal at the minimum knee extension. The results also showed the MF285 at ergonomic level had the lowest level in relation to the other three tractors, thereby increasing disturbance in the knee joint.

Conflict of interest

The authors declare that there are no conflicts of interest.

REFERENCES

1. Cavallo E, Ferrari E, Bollani L, Coccia M. Strategic management implications for the adoption of technological innovations in agricultural tractor: the role of scale factors and environmental attitude. *Tech Anal Strat Manag*. 2014;26 (7):765–779.
2. Dewangan KN, Owary C, Datta RK. Anthropometric data of female farm workers from north eastern India and design of hand tools of the hilly region. *J Ind Ergon*. 2008;38(1):90–100.
3. Fathallah FA, Chang JH, Berg RL, Pickett W, Marlenga B. Forces required to operate controls on farm tractors: implications for young operators. *Ergonomics*. 2008;51 (7):1096–1108.
4. Kumar A, Bhaskar G, Singh JK. Assessment of controls layout of Indian tractors. *Appl Ergon*. 2009;40(1):91–102.
5. Mehta CR, Pandey MM, Tiwari PS, Gite LP, Khadatkar A. Tractor controls actuating force limits for Indian operators. *Ind Health*. 2011;49(4):523–533.
6. Mehta CR, Tiwari PS, Rokade S, et al. Leg strength of Indian operators in the operation of tractor pedals. *Int J Ind Ergon*. 2007;37(4):283–289.
7. Mehta CR, Tewari VK. Biomechanical model to predict loads on lumbar vertebra of a tractor operator. *Int J Ind Ergon*. 2015;47:104–116.
8. Mokdad M. Anthropometric study of Algerian farmers. *J Ind Ergon*. 2002;29(6):331–341.
9. Victor VM, Nath S, Verma A. Anthropometric survey of Indian farm workers to approach ergonomics in agricultural machinery design. *Appl Ergon*. 2002;33(6):579–581.
10. Gomez MI, Hwang S, Stark AD, May JJ, Hallman EM, Pantea CI. An analysis of self-reported joint pain among New York farmers. *J Agric Saf Health*. 2003;9(2):143–157.
11. Tiwari PS, Gite LP, Majumder J, Pharade SC, Singh VV. Push/ pull strength of agricultural workers in central India. *Int J Ind Ergon*. 2010;40(1):1–7.
12. Ferrari E, Cavallo E. Operators' perception of comfort in two tractor cabs. *J Agric Saf Health*. 2013;19(1):3–18.
13. Ye Z, Bai Q, Li X. Agricultural implementation security research based on ergonomics. *J Converg Inf Technol*. 2012;7 (20):65–71.
14. Shydlovskyi AK, Pavlov VB, Tretiak MV. The possibility of creating vehicles for agricultural purposes with the electric transmission systems and combo power supply. *Tech Electrodyn*. (1):2012;(1):46–48.
15. Kong D, Zhang S, Zhu Z, Yang M. Driver's fatigue evaluation and analysis in mechanized sowing work. *Trans Chin Soc Agric Mach*. 2008;39(8):74–78.
16. Dewangan KN, Owary C, Datta RK. Anthropometry of male agricultural workers of north-eastern India and its use in design of agricultural tools and equipment. *J Ind Ergon*. 2010;40(5):560–573.
17. Qiu Y, Zhu Z, Mao E, et al. Virtual ergonomics design and evaluation of agricultural equipment cab. *Trans Chin Soc Agric Eng*. 2011;27(3):117–121.
18. Dewangan KN, Gogoi G, Owary C, Gorate DU. Isometric muscle strength of male agricultural workers of India and the design of tractor controls. *J Ind Ergon*. 2010;40(5):484–491.
19. Drakopoulos D, Mann DD. Development of a method for ergonomic assessment of a control layout in tractors. In: Bust PD, ed. In: *Contemporary Ergonomics*. Abingdon, Oxford: Taylor and Francis; 2006:611–615.
20. Widana IK. Redesigning tractors for reduced soil cultivation and increased productivity in the agricultural sector in Bali Indonesia. In: Shih YC, Liang SFM, eds. In: *Ergonomics in Asia: Development Opportunities and Challenges – Selected Papers of the 2nd East Asian Ergonomics Federation Symposium (EAEFS 2011) National Tsing Hua University*London: Taylor & Francis; 2012 :31–35.
21. Chaturvedi V, Kumar A, Singh JK. Power tiller: vibration magnitudes and intervention development for vibration reduction. *Appl Ergon*. 2012;43(5):891–901.
22. Zatsirosky VM. *Kinematics of Human Motion*. Champaign: Human Kinetics; 2002.
23. Lehto MR, Buck JR. *Introduction to Human Factors and Ergonomics for Engineers*. New York: CRC Press; 2008.
24. Shan G, Bohn C. Anthropometrical data and coefficients of regression related to gender and race. *Appl Ergon*. 2003; 34(4):327–337.