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An ergonomic evaluation of clutch pedal in a few models of common cars within taxi service lines in Tehran

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A B S T R A C T

Background and Purpose: Clutch pedal is one of the most important controlling systems of car, and as a foot controller, it would cause reduced comfort and fatigue in driver as well as vehicle safety decrease, because of the position and type of function mechanism, in case of inappropriate design. In current research, the clutch pedal comfort is investigated ergonomically in a few models of common cars within taxi service lines in Tehran. **Method:** in this sectional and applied study, 120 drivers from Tehran taxi lines were selected for study using stratified random sampling and an objective method (push and release force, frequency and duration of clutch pressing) as well as a subjective method, were used to investigate the fatigue and discomfort degree of clutch pressing. in the objective method, the push and release force were recorded using a piezoelectric dynamometer, while the duration of clutch pressing were noted using a micro switch called Data-logger. **Results:** According to results, there were significant difference in perceived discomfort after a work shift in all parts of the body involved in clutch pressing. Meanwhile, the highest discomfort was reported for lumbar (3.97) and knees (3.86) and the lowest one was for upper thigh muscle (1.45) and upper leg (1.98). Moreover, highest stated discomfort was for drivers of Peykan and Roa. About the force and frequency of clutch pressing, it was observed that the highest value was for Peykan. **Conclusion:** Results of this research show that Long-term use of clutch pedal in all tested cars, would cause significant discomfort after the work shift. Therefore, it's suggested to replace cars of taxi lines with automatic transmission types in long-term, and to replace Peykan and Roa cars which have the highest discomfort, with other models, in short-term.

Keywords: *Ergonomic Evaluation; Driving; Fatigue; Clutch Pressing.*

INTRODUCTION

Paying attention to driver comfort was first proposed for driver's safety and health. Moreover, this approach has turned to an important issue from the perspective of sale and market in recent decades with respect to costumers' expectations about comfort. For this reason, car design teams have faced to great challenges about costumer's comfort and satisfaction in recent years, and in this regard, serious measures have been taken place (1). Clutch pedal is one of the most important controlling systems of car, and as a foot controller, because of the position and type of function mechanism, in case of inappropriate design, it would cause reduced comfort and fatigue in driver as well as vehicle safety decrease (2).

According to current statistics in the country, more than 80,000 taxis including tour taxis and inline taxis are serving in Tehran city and among them, around 60,000 taxis consist from 4 types of car models (Peugeot 405- Peugeot Roa- Samand – Peykan)(3). Since almost all taxis inside the country are manual transmission cars whose drivers use equipment of them including clutch, more than any other users, dealing with comfort, safety and health of taxi drivers is of great importance than other ordinary drivers. Discomfort and dissatisfaction for this large group of drivers influence not only on themselves, but also on other people of society and important indicators such as traffic, accidents and etc. (4)

Literature review shows that despite great importance of driver's safety and comfort, there are little applied studies in this field around the world, and most of studies inside the country are related to the prevalence and risk of musculoskeletal disorders factors among drivers and they are not specific to car's clutch system discomfort.

In 2011, Izadpanah et al, performed a study about prevalence and risk of musculoskeletal disorders factors among taxi drivers of inside and outside the city of Andisheh, and it had been determined that the risk of musculoskeletal disorders is high among taxi drivers, since there are long-term exposure to vibration, steady work and sedentary, prolonged sitting, and inappropriate postures during the driving. In addition, it's observed in this study that the highest amounts of musculoskeletal disorders prevalence are for lumbar (51.2%) and knees (41.8%). Work environment has the greatest share in creating pain in lumbar (91.1%), shoulder (89%), neck (92.7%) and wrist (96.8%) (5).

Brook et al from Bradford University of England, investigated about measurement system of ergonomic data for driver-pedal interaction. They did that through a combination of data including goniometer measurements, position of driver, data from electromyography method, pressure pads system and GPS system. They concluded that these tools can improve our understanding about involving factors in pedals comfort (6).

In another study, Lee et al in 2012 studied about the effect of clutch pedal on car comfort. According to results of this study, gradual movement of pedal activation point between 100-125 mm and pedal force between 85-100 cause more acceptable comfort (7).

In a research performed by Wang et al in 2002 for biomechanical evaluation of car's clutch pedal comfort function, they concluded that there would be more comfort if clutch pedal is designed in a way that foot raises in less extent during the starting phase of clutch pressing, and also lower joint work is experienced in knees and hip during pressing phase. In this research, it has used subjective perceived measures for general convenience (8).

Through another research by Giacomin et al aimed to measure comfort of using car's clutch pedal, they identified three parameters which were strictly dependent to subjective responses: Change in the angle between the trunk and thigh from the beginning of clutch pressing to the end of it, most obtained force during the covered distance by pedal, and the average slope of displacement-force graph during initial release phase. These three parameters are obtained by examining the correlation of subjective and objective criteria (9).

It was observed in a study by meta in 2006 on tractor operator foot power for working with pedal (Brake and Clutch), that the most necessary power for using a pedal is higher compared to Indian operators' foot power. These measurements were performed on Tractor mock-up model and objective and subjective tools were used for evaluation. The most required force for using brake and clutch pedal was suggested between 280-320 Newton (10).

Determining subjective perception of driver about clutch pedal system comfort and examining its correlation with objective parameters such as anthropometric dimensions, forces and muscle activity involved in clutch set and etc., are among important factors in investigating effective elements on fatigue and perceiving clutch pressing comfort and driver general comfort. In this research, we aim to investigate driver comfort and functionality and easiness of clutch pedal in a few car models within the group of taxi drivers.

Method:

This research is a sectional and applied study which investigate about taxi drivers comfort while working with clutch pedal and also comparing comfort of four car models clutch pedal among Iran Khodro co. products (Peugeot 405, Samand, Roa and Peykan) within taxi drivers in Tehran city.

Current study is conducted through two completely separated parts:

A) Evaluation of drivers' mental distress toward car's clutch pedal

In this stage of study, 120 of Tehran city taxi drivers, which were willing to participate in the study, were selected using stratified random sampling. In this step, by referring to Tehran Taxi Services information, it was determined that there are 722 taxi lines in Tehran. Using random numbers table, 120 lines were selected from existing 722 one, in a way that all of four car types (Peykan, Samand, Peugeot 405, RD) have same share in selected sample. Indeed, total sample size (120) divided among classes (type of vehicle) based on population.

Data was collected using questionnaire after obtaining written consent, in two previous steps and after the work shift. The used questionnaire includes a part about demographic characteristics (age, education, weight, height, experience,…) and a part about body map (Figure 1) in order to determine perceived discomfort about the clutch pedal in 11 parts involved with clutch pressing (Metatarsal, Calcaneus, ankles, upper leg, Lower Leg, knee, Upper thigh, Lower Thigh, Ischia, lumbar, and Thoracic part) which must be completed in two steps, before and after the work shift. The participants were asked to determine their perceived discomfort using six items in the form of Likert scale (0=no pain and discomfort, 5=very high pain and discomfort). The body map was created based on previous studies (9). It's content validity was confirmed using expert opinions and its reliability was confirmed after the pilot study on 10 drivers with the Cronbach's alpha coefficient 0.784.

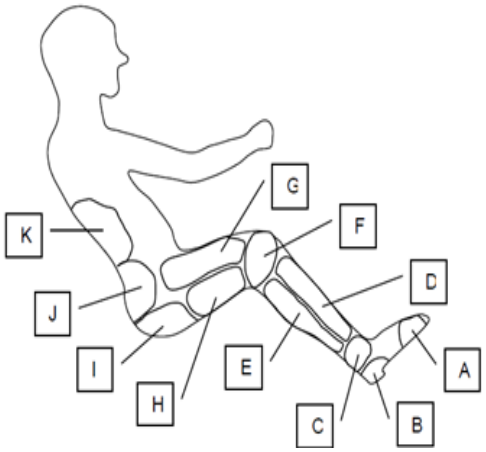

Figure 1. Body regions evaluated in the body part discomfort form

B) Professional evaluation of fatigue and discomfort levels in clutch pressing by two objective and subjective methods

In this stage of study, 15 of drivers were selected and studied in a way that represent target population and cover considered anthropometric percentile (three anthropometric percentiles 5, 50 and 95). In subjective evaluation of drivers about clutch discomfort, a questionnaire is used according to the last section. In the objective evaluation, biomechanical variables including related anthropometric dimensions (Hip-knee length, foot width, foot length, knee height, and popliteal height) and the angles of joints trunk-thigh, thigh-knee and ankle were measured in static and dynamic states. It was done in a way that after settling the driver inside the car, he was asked to perform configuration about car package (seat distance and angle) and select preferred body position. In this state, required dynamic anthropometric dimension such as ankle angle, knee-thigh angle, and trunk-thigh were measured for two states including: 1) state that pedal has passed 0% of sweep (clutch pedal on highest point) and 2) state that pedal has passed 100% of sweep (lowest point). Moreover, mechanical evaluation of selected cars including required force for clutch pressing, frequency of clutch pressing and duration of clutch pressing were also performed.

Let's assume that X_0 is the released pedal state and X1 is the pressed pedal state. There are applied forces during state X0 to X1 and on the way back. These information are obtained by installing a piezoelectric dynamometer LAU220,500 lb. (made by Futek co) (Figure 2) in the car in order to measure sweep forces. A micro-switch named Data-Logger was also designed to evaluate the frequency and duration of clutch pressing.

Mechanical evaluations were conducted in two general stages:

Static Test: where measurements were done when the car is turned off and drivers press clutch pedal in determined frequency and time, and necessary data were achieved during this.

Dynamic Test: in this stage, a personal evaluation from body comfort status were accomplished using a questionnaire before beginning to drive in routine routes by each one of participant, as well as after the work shift with the same questionnaire. By the way, quantitative variables such as frequency and duration was collected using the micro switch and designed sensors and a sensor data recording software (produced by IPCO lab).

Figure 2. FUTEK dynamometer

Figure 3. Data logger, data logger and switch Limited installed in the vehicle

Results:

According to the results, Mean ± SD of drivers' age is 47±9. 28% of them had academic educations. Mean ± SD of driving experience is 10±7 years. 70% of them are smokers and mean± SD of driving hours per day equals to 9±2. mean± SD of car age is 10±4. Moreover, 64 of them (i.e. 53%) suffered from sleep disorder. Anthropometric data related to participants are presented in Table 1.

Table 1. anthropometric taxi drivers in Tehran lines (in cm)

car type		Peugeot 405				Peugeot Roa				peykan				Samand			
Percentile		5	50	50	95	5	50	50	95	5	50	50	95	5	50	50	95
Height		162	171	173	190	159	172	174	190	156	175	171	184	163	175	175	195
Knee height		44	56	53	57	46	51	51	60	48	51	55	60	48	56	51	60
Popliteal height		38	43	42	45	37	42	39	50	34	43	39	48	37	39	43	49
foot length		20	26	25	29	20	23	24	31	22	23	25	29	21	26	24	29
foot width		9	9	11	12	7	11	9	12	9	9	11	11	8	11	9	12
Hip-knee length		52	60	55	66	55	58	60	63	54	55	60	63	55	57	55	66
Angle before pressing the clutch	Ankle	96	80	87	85	80	85	87	96	70	81	73	78	87	85	80	96
	thigh-knee	91	102	91	106	97	101	92	116	91	92	96	89	114	117	106	99
	trunk-thigh	106	97	107	95	94	95	97	97	87	89	84	80	103	96	100	93
Angle after pressing the clutch	Ankle	100	100	102	102	101	102	101	102	96	95	95	84	101	102	100	100
	thigh-knee	129	133	117	122	135	125	126	134	145	128	132	121	118	132	132	130
	trunk-thigh	111	104	111	111	114	118	112	100	109	110	108	120	105	106	107	105

About the frequency and duration of clutch pressing, as it can be seen in table 2, the most frequency and duration was for Peykan in all long, medium, low traffic and heavy traffic routes. Results from dynamometer also demonstrate that required force for clutch pressing for Peykan, Peugeot RD, 405 and Samand is 18, 17, 13.5 and 12.5 Kg, respectively.

Table 2. Frequency and duration of clutch during a working shift by Type of Vehicle

car type	Kind of route	Frequency (number)	Duration (min)
peykan	Long	928	42/5
	Medium	874	40/4
	Low traffic	827	40/4
	Heavy traffic	946	43/3
Peugeot 405	Long	717	32/6
	Medium	730	33/0
	Low traffic	698	32/0
	Heavy traffic	749	34/9
Samand	Long	624	28/6
	Medium	656	20/5
	Low traffic	582	26/7
	Heavy traffic	764	35/0
Peugeot Roa	Long	782	0
	Medium	814	37/4
	Low traffic	698	32/0
	Heavy traffic	836	38/5

Comparison of discomfort level, before and after work shift using Wilcoxon test showed statistically significant difference. The amount of perceived discomfort by drivers in 11 parts of body involved in clutch pressing, shows that there are significant difference in perceived discomfort, before and after the work shift (P-Value<0.001). Moreover, the average of most discomfort was for lumbar (3.98) and knees (3.73), and the lowest one was reported for upper thigh (1.46) and upper leg (1.98). (Table 3).

Table 3. Comparison of average comfort of clutch pedal before and After the work shifts using the Wilcoxon test

Row	Part of body	step	Average	Standard deviation	P-value
1	Thoracic	before working shift	0/38	0/49	*0/000
		after working shift	3/34	1/01	
2	Lumbar	before working shift	1/21	0/78	*0/000
		after working shift	3/98	1/05	
3	Upper thigh	before working shift	0/14	0/35	*0/000
		after working shift	1/46	0/95	
4	Knee	before working shift	1/01	0/77	*0/000
		after working shift	3/73	0/87	
5	Upper Leg	before working shift	0/34	0/48	*0/000
		after working shift	1/98	1/15	
6	Metatarsal	before working shift	0/89	0/75	*0/000
		after working shift	3/19	1/38	
7	Ankle	before working shift	0/48	0/53	*0/000
		after working shift	2/78	7	
8	Calcaneus	before working shift	0/31	0/50	*0/000
		after working shift	2/30	1/31	
9	Lower Leg	before working shift	0/23	0/42	*0/000
		after working shift	2/97	1/08	
10	Lower Thigh	before working shift	0/33	0/47	*0/000
		after working shift	2/77	1/02	
11	Ischia	before working shift	0/38	0/49	*0/000
		after working shift	3/18	1/39	

It was determined using Kruskal-Wallis test that there is no significant difference in perceived discomfort level among drivers between 5, 50 and 95 percentiles (Table 4). The Kruskal-Wallis test also used in order to examine perceived discomfort level among drivers in 11 determined body area based on the car. Results of this test showed that there is significant difference among cars in three areas of knees, lumbar and thoracic. With more detailed examination, the level of discomfort in the mentioned three parts, had a significant difference in Peykan, comparing to three other cars (Table 4). It's also observed that the most discomfort declared by drivers of Peykan, following by Peugeot Roa, Samand and Peugeot 405. Moreover, the most discomfort was declared by 95 percentiles.

Table 4. Comparison of discomfort in various body parts before and after using the clutch in terms of percentiles and vehicles of choice using the Kruskal-Wallis test

Row	Compare discomfort and vehicle type	P-value By Percentile	P-value By car
1	Thoracic -before work	0/932	0/739
2	Thoracic -after work	0/749	0/013*
3	Lumbar -before work	0/636	0/109
4	Lumbar - after work	0/599	0/006*
5	Upper thigh -before work	0/906	0/607
6	Upper thigh- after work	0/581	0/409
7	Knee-before work	0/147	0/057
8	Knee-after work	0/136	0/004*
9	Upper Leg-before work	0/382	0/384
10	Upper Leg-after work	0/721	0/326
11	Metatarsal - before work	0/581	0/380
12	Metatarsal - after work	0/459	0/228
13	Calcaneus - before work	0/159	0/252
14	Calcaneus - after work	0/776	0/301
15	Lower Leg- before work	0/515	0/209
16	Lower Leg-after work	0/762	0/765
17	Lower thigh-before work	0/921	0/687
18	Lower thigh -after work	0/712	0/327
19	Ankle-before work	0/15	0/555
20	Ankle-after work	0/44	0/294
21	Ischia -before work	0/184	0/498
22	Ischia -after work	0/194	0/506

The Pearson correlation test was used in order to investigate the relation between dynamic variables (force, frequency and duration of clutch pressing) and discomfort level of different body parts. Results showed that there is a significant relation between declared discomfort level by taxi drivers and some parts and dynamic variables. (Table 5).

Pearson test also used to examine the relationship between anthropometric variables (Hip-knee length, foot width, foot length, knee height, popliteal height). Results showed that there is no significant relationship between declared discomfort by taxi drivers and some anthropometric variables measured in this study.

Table 5. The relationship between dynamic variables with the perceived discomfort in the limbs

dynamic variables		Average of force	frequency	duration
Thoracic (before work)	Correlation	0/345	0/504	0/508
	P-value	0/190	0/047*	0/044*
Thoracic (after work)	Correlation	0/606	0/663	0/701
	P-value	0/013*	0/005*	0/002*
Lumbar (before work)	Correlation	0/596	0/516	0/523
	P-value	0/015*	0/041*	0/038*
Lumbar (after work)	Correlation	0/519	0/588	0/617
	P-value	0/040*	0/017*	0/011*
Upper thigh(before work)	Correlation	0/375	0/411	0/350
	P-value	0/153	0/114	0/184
Upper thigh(after work)	Correlation	0/256	0/091	0/010*
	P-value	0/339	0/738	0/970
Knee (before work)	Correlation	0/563	0/316	0/384
	P-value	0/023*	0/233	0/142
Knee (after work)	Correlation	0/589	0/548	0/611
	P-value	0/016*	0/028*	0/012*
Upper Leg(before work)	Correlation	0/460	0/180	0/211
	P-value	0/073	0/505	0/432
Upper Leg(after work)	Correlation	0/679	0/618	0/605
	P-value	0/004*	0/011*	0/013*
Metatarsal (before work)	Correlation	0/492	0/238	0/266
	P-value	0/053	0/375	0/319
Metatarsal (after work)	Correlation	0/585	0/374	0/427
	P-value	0/017*	0/153	0/099
Ankle (before work)	Correlation	0/422	0/127	0/240
	P-value	0/103	0/639	0/371
Ankle (after work)	Correlation	0/472	0/579	0/580
	P-value	0/065	0/019*	0/018*
Calcaneus (before work)	Correlation	0/713	0/575	0/566
	P-value	0/002*	0/020*	0/022*
Calcaneus (after work)	Correlation	0/559	0/608	0/555
	P-value	0/024*	0/012*	0/026*
Lower Leg (before work)	Correlation	0/047	0/110	0/074
	P-value	0/863	0/684	0/784
Lower Leg (after work)	Correlation	0/711	0/516	0/608
	P-value	0/002*	0/041*	0/012*
Lower Thigh (before work)	Correlation	0/409	0/550	0/493
	P-value	0/115	0/027*	0/052
Lower Thigh (after work)	Correlation	0/684	0/556	0/591
	P-value	0/003*	0/025*	0/016*
Ischia (before work)	Correlation	0/397	0/485	0/459
	P-value	0/127	0/057	0/074
Ischia (after work)	Correlation	0/550	0/526	0/554
	P-value	0/027*	0/036*	0/026*

Discussion and Conclusion

Current study is aimed to investigate clutch comfort among a few common car models in Taxi lines. Results of this research show that long-term use of clutch pedal in the high traffic Tehran city causes significant discomfort after the work shift in all tested cars. Moreover, the most discomfort was reported for the lumbar and knees. Obtained results are similar to results of Izadpanah et al. study. In Ziaei et al. work, the Nordic musculoskeletal disorders questionnaire and body discomfort chart was used and it was observed that the risk of musculoskeletal disorders are high among taxi drivers, since there are long-term exposure to vibration, steady work and sedentary, prolonged sitting, and inappropriate postures during the driving. In this research also the most musculoskeletal disorders were for lumbar (51.2%) and knees (41.8%), respectively. (5).

About the anthropometric dimensions, there were no significant relation between discomfort in different body parts and any of anthropometric dimensions of drivers. In the study of Sadeghi and Habibi (2009), results approved a significant relationship between popliteal length with upper and lower parts of lumbar, knees, front legs and inverse relationship with height and also the length of upper parts with discomfort of arm and elbow. This difference in results might be due to smaller sample size in this research.

According to this research results, regardless of the car model, it seems that the musculoskeletal discomforts are certain with respect to manual transmission system. Currently, the automotive industry in the world are moving toward using the cars with automatic transmission (automatic gearbox), while automatic transmission has great advantages and benefits comparing to manual ones. One of the most important benefits of automatic transmission cars is that gears are shifted automatically and reduces driver tasks specially for the people who are used to shift gears more frequently. Moreover, there is no special skill for drivers about it. In Automatic systems, the gears will shift automatically when it's necessary. In Cars with manual transmissions, excessive speed or lack of coordination between wheels speed specially for drivers with lower experience, would cause rapid depreciation of vehicles. While, in automatic transmission cars, the driver only needs gear status change and gas pedal, in order to drive the car. Among other benefits of automatic gearbox systems, are good driving functions in uphill and downhill slopes inside cities and also in roads.

On the other hand, using manual transmission cars requires gear shifts by hand and by the driver which this cause more movements for body and more consumed energy and also hurt driver focus, especially when it's done frequently. Houstons et al, examined number of gear shifting and activity of trapezius and deltoid muscles using Electromyography method. Results of their study showed that muscle cramp was occurred for more than half of examined drivers in mentioned muscles, after one hour of driving (12). Mozafari et al in 2014 reported a significant relationship between work experience in driving job and musculoskeletal Disorders especially in the lumbar part among truck drivers in Qom city (13). The research by Abeldo et al (2014) also shows that there is a direct relation in this field between long-term driving (more than 12 hours per day or more than 5 days per week) and increased WMSDs, in a way that the more driving hours by manual transmission cars, the more increased Effects of cramps in leg muscles and spine. Because, long-term use of gas and clutch pedal requires much movements of foot and leg muscles in a way that with clutch pressing, all muscles of foot become active and play their roles, and the ankle joint also becomes involved. As a result of pressure on foot and leg muscles, it will cause pressure on other parts of body and even muscles of lumbar and spine, which accelerates muscle diseases over time and creates much fatigue in drivers. Especially that much pressure on the knees would cause joint diseases for drivers (14). Currently, with increase in traffic in large cities, using automatic transmission cars is a necessity in a way that in some countries such as Australia, only cars with automatic transmission are authorized to move inside the city. Cars with automatic transmission cause accident decrease, while there is no much difference between manual and automatic transmission cars based on production cost and size of the gearbox and using automatic transmission gearboxes would decrease Vehicle Depreciation. With respect to what mentioned above, if there exist exact and correct planning inside the country, using automatic transmission cars would be an essential matter specially for car drivers with long-time driving, because it's good for city as well as citizens.

By exploring results of this research, it seems that performing similar researches is necessary in our country. In future works, researchers should attempt to compare and analyze among cars with manual and automatic transmissions. Of course by comparing existing cars in the market of Iran, it's worth mentioning that there are many limitations about automatic transmission cars inside the country. It's observed that the two large carmakers of the country, produce very few automatic products and those products doesn't have production stability and reasonable prices to use for a replacement in taxi service lines.

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