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Quantitative Analysis of Involuntary Movements as a Test of Comfort of a Car Seat: A Study of Man-Machine Interface

S.L. Malik[1], H.W. Juergens[2] and K. Helbig[2]
1. Department of Anthropology, University of Delhi, Delhi 110 007, India
2. Institute of Anthropology, University of Kiel, 2300 Kiel, Germany

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ABSTRACT Using quantitative analysis of involuntary movements, comfort/discomfort of a car seat, adjusted in three seat positions—based primarily on the backrest angle has been evaluated. The medial position (backrest angle-115 degree) has been found to be the most comfortable position followed by the backward inclined position (backrest angle 124-125 degree) and the forward inclined position (backrest angle 108-109 degree) respectively.

Individuals of different stature percentiles showed differences in comfort/discomfort with respect to the forward inclined and the backward inclined position, but all of them, irrespective of their stature percentiles, found the medial position to be the most comfortable. Involuntary movements increased in all the three seat positions during prolonged sitting. Application of the method has also been briefly discussed in other work situations.

Environment is the sum total of all external conditions and influences affecting the life, development, and ultimately the survival of an organism (De Santo, 1978). The microenvironment is that component of environment to which an organism is closely associated. The success of a species depends on its ability to meet the challanges of environment. Human beings, however, differ from other animals in the way they meet the challanges of environment. They combine biological power with the cultural endowment to encounter the environmental stresses (Malik and Bhattacharya, 1976). By the use of culture, man has developed the ability to manipulate the environment in order to satisfy not only his needs but also desires. Using technological abilities man has extensively modified the ecosystem. Consequently a large part of his microenvironment constitute his self-created environment in terms of machines and equipments. It is imperative that man should have congenial relationship with the machines and equipments he has designed. An appropriate man-machine relationship ensures safety, comfort and efficiency (Damon et al., 1966; Roebuck et al., 1975; Malik et al., 1984). Human factor is becoming increasingly important in designing products and workplace layouts (Vancott and Kinkade, 1972; Panero and Zelnik, 1979). For example, in an automobile, the position of seat and human factors determine the effectiveness with which the controls will be operated. This paper introduces the importance of man-machine interestationship taking designing of a car seat as a case study.

The application of scoring involuntary movements for measuring concentration is not new. Researches have shown that there is a wide inter-individual variations in both involuntary movements and concentration (Basedow, 1981; Schneider, 1984). Of several factors that influence this variation, the role of genetics, age, sex, physical and mental conditions and the environmental surroundings has been emphasized (Basedow, 1981; Helm, 1982; John, 1983).

Loss of concentration and increase in involuntary movements are the signs of discomfort and/or fatigue. In situations where only one of the external components is changed, the change in concentration, as assessed by the involuntary movements (IVM) may be directly associated to the comfrort/discomfort caused by that external component. As such IVM may be utilised for assessing the comparative comfort of a given environmental component (Helm, 1982; John, 1983). Despite its wide applicability, there have not been serious attempts to study comfort/discomfort in various situations and whenever such attempts have been made they have been largely limited to situations in which subjects were sitting idle. The probable reason may be that there is not only additions to the already long list of factors that affect involuntary movements making the relative contribution of each one undistinct, but it is also hard to differentiate between voluntary movements caused because of a given work from the involuntary movements. Their differentiation requires experience.

Earlier the members of the Department of Anthropology at University of Kiel had identified three seat positions (based on the backrest angle) indicating the optimal, the lower and the upper limit of the "comfortable zone", on the basis of subjective opinion of a series of individuals. For this purpose a seat was designed in laboratory with the possibility of adjusting numerous lengths and angles, such as, H point height (H point is the crossing point of the central axis of the trunk and the central axis of the thigh on SAE-manikin—a manikin designed by the Society of Automobile Engineers, USA, and which is widely used in the automobile industry), heel point-H point distance, angle of the seat surface, backrest angle, distance and angle of the streering wheel, angle and height of the foot pedal axis. In the selection of these three seat positions, the basic criteria used was the backrest angle. According to the selected backrest angle, seat surface angle, foot rest angle and the FP-HP distance (foot pedal - H point distance) were selected. The procedure followed was as under.

Each subject was asked to select, first of all, what he considered to be the most comfortable backrest angle while driving. In the next step the subject was asked to select seat surface angle, foot rest angle and FP-HP distance. This most comfortable position, based on the selection of backrest angle, was designated as the medial position (optimal/position 1). To establish the range of the "comfortable zone', each subject was asked to select the most forwardly inclined and the most backwardly inclined positions in which the subject continued to be comfortable. They were permitted to adjust seat by selecting the above mentioned distances and angles. The former position was designated as the Forward inclined (lower limit/position 2) and the latter as the Backward inclined (upper limit/position 3) position. Brief summary of the results of this work is presented in table 1.

Table 1: Summary of the results of qualitative analysis (Subject's opinion) of the three car seat positions

Seat Position	*Seat Component*	*Stature Percentile*		
		5th	*50th*	*95th*
Medial	Backrest angle	25	25	25
	Seat Surface Angle	14	16	18
	Foot Rest Angle	46	53	54
	FP-HP Distance	67cm	78cm	90cm
Forward Inclined	Backrest Angle	19	18	18
	Seat Surface Angle	14	16	17
	Foot Rest Angle	46	52	54
	FP-HP Distance	68cm	78cm	90cm
Backward Inclined	Backrest Angle	35	34	35
	Seat Surface Angle	15	17	19
	Foot Rest Angle	47	54	55
	FP-HP Distance	66cm	77cm	89cm

All the angles are in degrees

The objective of the present study is to study comprehensively, using the method of registrating involuntary movements, variation in comfort in three seat positions identified subjectively as the medial, lower and the upper limit of the "comfortable zone". Large differences are not expected as all the three seat positions are within the comfortable zone. The following are the specific aims of the present investigation:

—to study which one of the three seat positions, *i.e.* medial, forward inclined or the backward inclined is the most comfortable/discomfortable;

- —to compare the subjective (by interviewing subjects) and the objective method (by IVM) used for the assessment of comfort, and to test the concurrent validity of the IVM method as a consequence;
- —to investigate whether individuals of different sizes (in stature), *i.e.* 5th, 50th or 95th percentiles, feel equally comfortable or not in different seat positions; and finally
- —to find which of the three seat positions is the most comfortable during prolonged sitting (55 min.).

MATERIAL AND METHODS

Conditions close to that of while driving were created artificially in laboratory. The design of the set-up made it possible to adjust the seat in a desired position and simultaneously measure all the important distances and angles, such as the backrest angle, seat surface angle, footrest angle, and FP-HP distance.

The seat was set in three different positions based on the backrest and the seat surface angle. Subjects of different stature percentiles used different back rest angles (Table 1). Next, subjects were allowed to select FP-HP distance, seat surface angle and foot rest angle as per their choice but within a narrow range of 'comfortable zone' established during the subjective analysis. Selection of seat position was randomised for each subject to determine the order in which a subject would select a particular seat position, *i.e.* in which seat position the subject would sit first, second or the last. Subjects were asked to occupy themselves with a video-driving-simulator, displayed on a monitor kept in front. This arrangement served two purposes; firstly it kept subjects busy and secondly it provided conditions close to that of while driving.

Five persons of 95th percentile, three individuals of 50th percentile, and six persons of 5th percentile according to stature were selected. This type of sampling (selective) is not only permissible but often desirable and recommendable in the field of industrial anthropology, specially if the subjects of known percentile values from the user's population are available. The subjects ranged in age from 18 to 48 years.

A recording of 55 min. in each of the three seat positions, making a total recording of 165 min. per individual, was made. The camera was fixed in exact profile position nearly three metres away on the left side of the subject. Later, involuntary movements were scored by analysing the video recording following Basedow's method (Basedow, 1981), which may be summarized as under:

1) Big movements (given two scores):

- —head movements of more than 45 degree;
- —trunk movements leading to change in the sitting position;
- —hip movements;
- —movements of the arms and the legs of more than 45 degree.

2) Small movements (given one score):

- —head movements of less than 45 degree;
- —trunk movements of small magnitude not leading to change in position;
- —movements in the arms and the legs, but of less than 45 degree;
- —hand and feet movements.

The above scoring method was developed primarily for situations in which subjects were not asked to do any work and hence were not expected to make any voluntary movements. As such there were no voluntary movements which required to be differentiated from the involuntary movements. In the present design, however, the subjects were given a task to perform, *i.e.* to move the steering as per the requirement of the video driving simulator, which was being displayed on the monitor placed in front. Consequently the subjects made both voluntary (due to the given work) and involuntary (due to discomfort) movements. The two needed to be distinguished to score only the latter to examine discomfort. A mistake in differntiating the two kinds of movements could cause error in scoring and hence in interpretation. Nonetheless it did not pose a serious problem firstly because with a little bit of experience it was possible to differntiate between the voluntary and involuntary movements. Secondly this error could be, and was averted, using the following scoring pattern:

The involuntary movements were scored body segment-wise for the three seat positions. For example, the involuntary movements in head were scored for the three seat positions followed by scoring IVM in the trunk, hips and so on, rather than scoring IVM separately for each seat position for all the body segments. Randomisation of three seat positions in scoring IVM further authenticated comparisons.

Records of IVM were made for each body segment in three seat positions for 55 minutes duration with five minutes interval (0 to 5 minutes, 5 to 10 minutes, and so on). Total IVM made by each body part in each time interval and in each seat position were calculated thereafter. Sum of IVM made in total 55 minutes were also recorded.

RESULTS AND DISCUSSION

Comparison of Three Seat Positions

Analysis of IVM suggests that individuals make more movements in the forward inclined position than in either the medial or the backward inclined position; the difference being statistically significant between the medial and the forward inclined position (Table 2). Though the difference between the medial and the backward position is only marginal but the inter-individual variations (as evident from the within group variance/standard deviation) is distinctively higher in the backward inclined position than in the medial position (Fig. 1). In other words the range of discomfort encountered by different subjects is much higher in the backward inclined position than in the medial position. As such the medial position is slightly better than the backward inclined position and should be the obvious choice, in case of a non-adjustable seat.

It is noteworthy that the inter-individual variation in IVM is so high (between 80 and 1517) that, atleast to some extent, it is likely to mask the intra-individual or inter-positional variations. Therefore, for making any meaningful comparison between three seat positions, some kind of within standardisation is necessary. To do so, the scores of each person was standardised in a way that the IVM made in one of the three seat position by an individual were represented as a percentage ratio of the sum total of IVM made by him collectively in three seat positions using the undermentioned index (IVM Index) :

$$\frac{\text{IVM in Medical/Forward/Backward position}}{\text{Sum total of IVM made in three seat positions}}$$

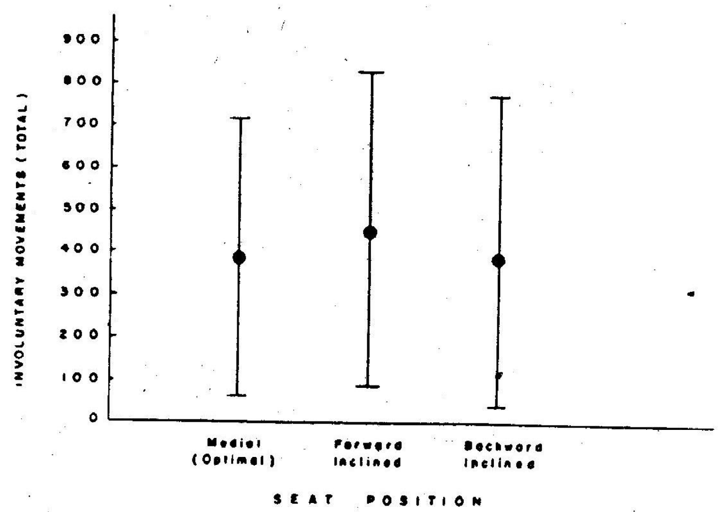

Fig. 1. Mean values and standard deviation of total involuntary movements in three seat positions (for details of seat positions see Table 1)

An index value which is higher/lower than 33.33 indicates higher/ lower level of discomfort in a particular seat position. Calculation of this index permitted comparison of three seat positions as inter-individual variations in scores did not influence comparison any further. The results were further authenticated by applying 'Pair t test' to the IVM made in each seat position.

In the total sample, the mean value of IVM index is the lowest in the medial position, followed by the backward inclined and the forward inclined positions respectively. As such the medial position is the most comfortable and the forward inclined position is the least comfortable (Fig. 2).

Comparison of Three Seat Positions: Stature Percentile Groups

In order to find whether individuals of different heights feel equally comfortable or not, the sample was divided in three percentile groups according to stature, *viz.* 5th, 50th and 95th percentiles. IVM index analysis reveals that the medial position is comfortable to individuals of all heights, whereas the forward inclined position is the least comfortable to all the individuals, irrespective of their stature (Fig. 3). The degree of discomfort in the forward inclined position is, however, the minimum in shorter individuals, which tend to increase with increase in body height. The backward inclined position, though not as comfortable to the individuals of 5th or 50th percentile group as to the 95th percentile group, but was well within the comfortable zone, if a margin of range was given to the comfortable zone (IVM analysis index : 32.66 - 34.00). The results of IVM and pair t test confirm the above trend and finding (Table 2). The difference between the forward inclined and the medial position reaches the level of significace only in 95th percentile group and not in 5th or 50th percentile group.

Table 2: Inter-positional (Pairwise) comparison of involuntary movements in subjects of different stature percentiles using pair t test

Group	*Seat Position*	*Value of t*	*Probability*	*Remarks*
Total Sample	ML x FI	2.52	.026	S
	ML x BI	1.84	.088	NS
	BI x FI	0.04	.966	NS
Short Statured (5th Percentile)	ML x FI	0.44	.678	NS
	ML x FI	0.36	.730	NS
	BI x FI	0.30	.736	NS
Medium Statured (50th Percentile)	ML x FI	1.60	.250	NS
	ML x BI	1.92	.195	NS
	BL x FI	1.43	.288	NS
Tall Statured (95th Percentile)	ML x FI	2.27	.085	NS
	ML x BI	2.83	.047	S
	BI x FI	0.16	.883	NS

S/NS indicate Significant/Non-significant at 5% probability level
ML-Medial Position; FI-Forward Inclined: BI-Backward Inclined

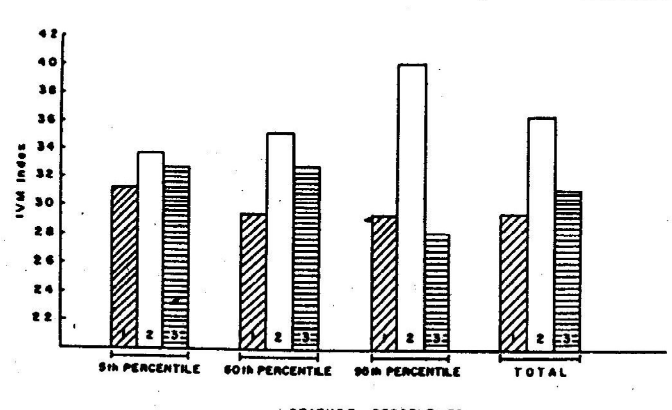

Fig. 2. Distribution of IVM index in three seat positions according to stature percentiles. (1) Medial (2) Forward inclined (3) Backward inclined

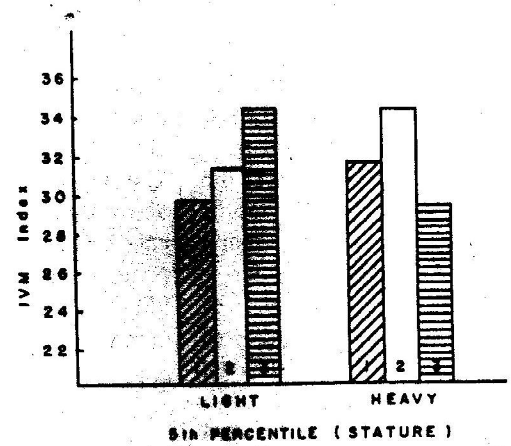

Fig. 3. Distribution of IVM index in light and heavy short statured (5th percentile) individuals. (1) Medial (2) Forward inclined (3) Backward inclined

When the sample of 5th percentile group (stature) was divided further into light and heavy group, according to body weight, it was deciphered that for the light and short people, the backward inclined position is the least comfortable, and the medial position is the most comfortable. Whereas for the heavy and short people, the forward inclined position is the least comfortable, and the backward inclined position is the most comfortable (Fig. 3). It can be concluded that weight, like stature, seems to be one of the principal components involved in determining comfort in different seat positions. Lack of sufficient data in different weight percentile did not allow us to probe any further into this problem.

Comparison of Three Seat Positions: Fatigue Over Time

With the advancement of time, there is a rise, though irregular, in IVM in all the three positions (Fig. 4). It indicates, that there is an increase in fatigue with time in all the three seat positions. Total IVM made are throughout higher in the forward-inclined seat position than in the medial position. With few exceptions this is also true for the backward-inclined position, although the difference between the backward inclined and the medial is much less as compared to that of between the medial and the forward inclined. The ratio of IVM in 40-55 min. to IVM in 0-15 min. shows a rise of 40 to 50 % (Table 3). This ratio could be taken as an indicator of magnitide of increase in fatigue and/or discomfort. This ratio (increase in IVM) is the least in the forward inclined position, followed by the medial and the backward position respectively. It is noteworthy that the increase in IVM during prolonged sitting is the minimum in the forward inclined position, despite it being the least comfortable position. A reason which can be advanced is that IVM in the forward inclined position are much higher right from the beginning and continue to be so throughout the whole period so that the increasee in IVM is not that fast.

Table 3: Inter-positional (Pairwise) comparison of involuntary movements in light and heavy, short statured individuals (5th percentile) using pair t test

Group	*Seat Position*	*Value of t*	*Probability*	*Remarks*
Short Statured (5th Percentile) Light Weight	ML x FI	0.53	.650	NS
	ML x BI	1.02	.416	NS
	BI X FI	1.80	.214	NS
Short Statured (5th Percentile) Heavy Weight	ML x FI	1.71	.230	NS
	ML x BI	0.88	.473	NS
	BI x FI	0.67	.570	NS

NS indicate Non-significant at 5% probability level
ML-Medial Position; FI-Forward Inclined: BI-Backward Inclined

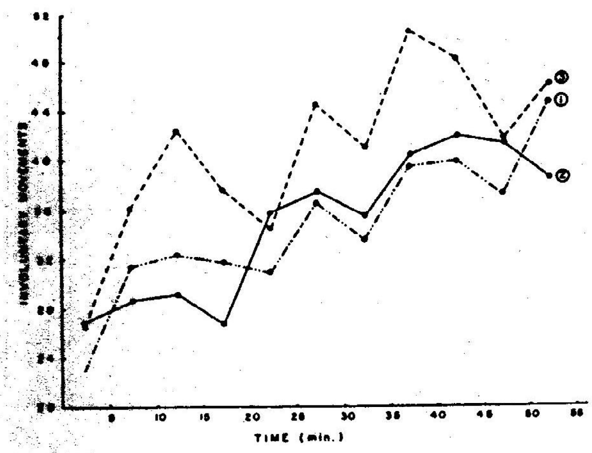

Fig. 4. Effect of prolonged sitting (0 to 55 minutes) on IVM in three seat positions, *viz.* the Medial (dash and dots), the Forward inclined (broken lines) and the Backward inclined (solid lines)

Comparison of Three Seat Positions: Different Body Segments

Analysis of IVM in different body segments shows, that the maximum number of involuntary movements are made in the head, and the least in the hips (Fig. 5). Comparison of IVM in various body segments once again reveals that the IVMs are the maximum in the forward inclined seat position. The differences are much less between the backward and the medial, and are somtimes overlapping, but they are definitely

Table 4: Increase in involuntary movements during prolonged sitting in three seat positions

Position	Involuntary Movements 0 - 15 min.		Involuntary Movements 40 - 55 min.		IVM Ratio (in %age)	
	Mean	*S.D.*	*Mean*	*S.D.*	*Mean*	*S.D.*
Medial	87.9	85.0	123.6	99.7	148.5	48.5
Forward-Inclined	106.9	99.7	138.2	104.8	140.1	35.3
Backward-Inclined	85.9	76.0	126.5	112.4	149.1	61.5

IVM Ration = [IVM (40-45 min.)/IVM (0-15 min.)] x 100

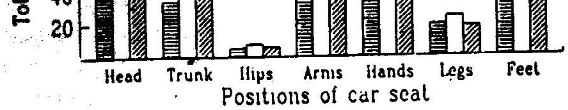

Fig. 5. Total involuntary movements in different body parts in three seat positons, *viz.* the Medial (bars with horizontal lines), the Forward inclined (empty bars) and the backward inclined (bars with oblique lines)

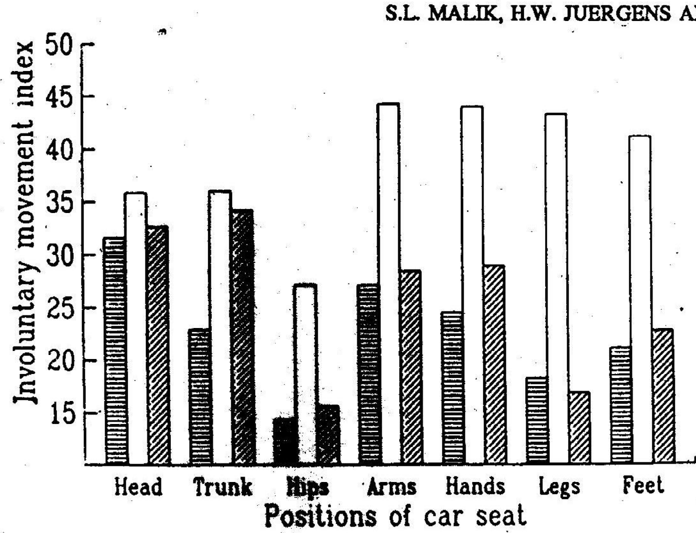

Fig. 6. Distribution of IVM index in different body parts in three seat positions, *viz.* the Medial (bars with horizontal lines), the Forward inclined (empty bars) and the Backward inclined (bars with oblique lines)

more in head, trunk and hips in the backward inclined position than in the medial position (Fig. 6). As movements in these body parts are of relatively greater importance from the point of view of assessment of discomfort, therefore in this respect too, the medial position seems to be a little better than the backward inclined seat position.

CONCLUSIONS

From the foregoing results and discussion it has emerged that, firstly out of the three seat positons, the forward inclined position (backrest angle between 108 and 109 degree) was the least comfortable, and the medial position (backrest angle 115 degree) was the most comfortable as assessed by the involuntary movements. The difference between the backward inclined (backrest angle between 124 and 125 degree) and the medial position was, none the less, minimal.

Secondly, individuals of different sizes did not feel equally comfortable in different seat position. Tall individuals for example, had a special liking and felt more comfortable in the backward inclined position of the seat.

Thirdly, during prolonged sitting (55 minutes), fatigue increased over time, as expected. There was much more discomfort felt in the forward inclined position than either medial or the backward inclined position. Contrary to the expectation, however, the increase in discomfort was the least in the forward inclined position.

Fourthly, the analysis of IVM in different body parts confirmed the finding that the medial position was the most comfortable followed by the backward inclined, and the forward inclined respectively. Although the differences between the medial and the backward inclined positions were marginal in most body parts, but they were more in the backward inclined position, at least in the crucial (from the point of view of discomfort) ones, *i.e.* trunk, hips and head.

Finally it may be concluded, that the method of involuntary movements could be used as an efficient tool in assessing comfort. Specially when combined with information based on the interviews or opinions of subjects, it can enhance the value of the information by bringing objectivity to the subject's opinion and quantifying them. As such it can be more effectively used in making comparisons. The application of this method is not only limited to testing comfort of car seats, which has been presented here as an example. It has much wider applications in the field of industrial anthropology or ergonomics, where comfort has to be evaluated, such as testing beds or chairs. Other applications include testing comfort in different environment or work conditions, for examples in examining effect of temperature, humidity or other climatic factors on comfort. It can also be used in finding user's comfort in a man-machine interface by making a comparison of different machines or even the same machine set in different positions. For example, to find out what could be the appropriate distance between the table and chair height, while using a keyboard (typewriter or computer keyboard) or should distance be the same for individuals of all sizes? These are only some of the many examples which could be cited indicating the application of IVM method in the field of ergonomics or kinanthropometry.

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