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UNDERSTANDING THE EFFECT OF NOISE, VIBRATION AND SEAT DISCOMFORT TOWARDS A PASSENGER'S VEHICLE DRIVER THROUGH SELF-REPORTED SURVEY

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Abstract. An online questionnaire-based survey was conducted to gather information regarding driving discomfort of Malaysian passengers' vehicle driver. The discomfort factors investigated were noise, vibration and driver's seat. For the noise and vibration, it was found that women respondents feel more discomfort for vibration related factors while men respondents feel more discomfort for noise related factors. There was no significant difference between discomfort for noise and vibration during idle or accelerating conditions. Regarding driver's seat discomfort, it was found that more respondents had experienced discomfort or pain at the upper back. The differences of discomfort responses for different body parts between men and women drivers were mainly caused by anthropometrical factor. Both men and women drivers experience noise, vibration and seat discomfort, however with different levels of sensitivity for different factors and body parts. From this study, no significant difference was found on overall discomfort between genders. Although it is self-reported, the result is in-line with the findings from the literatures.

Keywords: Noise; vibration; driver seat; discomfort; survey; questionnaire

Abstrak. Satu tinjauan berasaskan soal selidik atas talian telah dijalankan untuk mendapatkan maklumat berkenaan ketidakselesaan pemanduan kenderaan penumpang pemandu Malaysia. Faktor ketidakselesaan yang diselidiki ialah hingar, getaran dan tempat duduk pemandu. Untuk hingar dan getaran, didapati bahawa responden perempuan lebih tidak selesa untuk faktor berkaitan dengan getaran manakala responden lelaki lebih tidak selesa untuk faktor berkaitan hingar. Tiada perbezaan ketara antara ketidakselesaan untuk hingar dan getaran ketika pegun mahupun memecut. Berkenaan ketidakselesaan tempat duduk pemandu, didapati bahawa lebih ramai responden mengalami ketidakselesaan atau kesakitan di bahagian atas belakang. Perbezaan untuk respon ketidakselesaan bagi bahagian badan berlainan antara pemandu lelaki dan perempuan terutamanya disebabkan oleh faktor antropometri. Kedua-dua pemandu lelaki dan perempuan mengalami ketidakselesaan akibat hingar, getaran dan tempat duduk tetapi dengan sensitiviti yang berbeza untuk faktor dan bahagian tubuh yang berlainan. Daripada kajian ini, tiada perbezaan ketara yang dijumpai untuk kesuluruhan ketidakselesaan antara

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kedua-dua jantina. Meskipun ia berbentuk laporan kendiri, keputusannya adalah selari dengan penemuan daripada kajian-kajian literatur.

Kata kunci: Hingar; getaran; tempat duduk pemandu; ketidakselesaan; tinjauan; soal selidik

1.0 INTRODUCTION

The best way to understand customer's perception is through surveys [1]. In this case, the customer is the passenger's vehicle driver. Surveys are common in the preliminary stage of discomfort study in order to learn about the target population's perception on the matter [2-4]. There is yet a standard methodology in measuring people's perceptions hence reduces the comparability of statistics developed by different researchers [3, 5].

It is undeniable that today's car is much more comfortable and has improved so much in many ways including noise, vibration and seat aspects. It has been shown in many discomfort studies that responses were usually high between slight to moderate discomfort only (for continuous scale value < 4 mostly using Borg CR10 scale) and very rarely at the most extreme of the discomfort scale [6-8]. In Malaysian automotive engineering scenario, comfort or discomfort study is still in its infancy stage. It has been suggested in the literature that to develop a scientific framework model of automobile seat comfort, data from all parts of the world is crucial [9] especially that Malaysia has its own automotive industry. Most literatures [1,3,4,6-8,10,11] showed that driving discomfort surveys investigated either seat discomfort or musculoskeletal disorders. Noise and vibration were asked only as one part of the total vehicle evaluation and were regarded as 'other sources of seated discomfort' [3,12,13], whereas vehicle seat discomfort is very much affected by vibration. On the other hand in automotive, vibration and noise are usually considered as one item known as noise, vibration and harshness (NVH). Hence, it is important that all the three discomfort factors should be investigated together. This is a preliminary effort to understand the effect of noise, vibration and seat discomfort towards Malaysian passengers' vehicle drivers. It is entirely a memory-based, self-reported survey.

The attempts were to understand the Malaysian drivers' general perspective on noise, vibration and seat discomforts in driving. It is interesting to know whether noise and vibration have more effects during idle or accelerating. Secondly, whether the lumbar area is the most discomfort area of the body when Malaysian drivers are concerned as suggested in literature [7, 8]. The final objective is to study whether gender has significant effect on the overall discomfort factors investigated in the survey.

2.0 METHODOLOGY

There are many definitions for survey and it is entirely dependent on the research context [14]. Smith *et al.* [3] clearly suggested method of developing an automotive seating discomfort questionnaire. The most important part in questionnaire design is the items selection. The readability score for this questionnaire are found to be high as the items selection were based from previous literatures [4, 6, 15, 16]. Reliability was assessed using internal consistency of the survey. Low correlation between some of the items in the questionnaire (probabilities less than 0.2) resulted in the deletion of three items from the pilot studies. Redeveloping the questionnaire involves re-wording the items, re-considering the type of rating scales and the verbal tags to be used as well as finding ways to minimize the survey length. The Cronbach's alpha increased from above 0.8 for pilot survey to above 0.9 for the actual survey which showed that the questionnaire is reliable.

The first pilot questionnaire was emailed to various local universities and few were approached with the paper-based. The second pilot questionnaire was internet-based but using the same subjects from pilot survey one who are invited through emails (N = same eleven subjects). Results from second and first pilot surveys were repeatable although using different methods. The actual survey was carried out as online-based survey (www.freeonlinesurveys.com) and the respondents were untraceable. Nevertheless, many respondents provide their name and corresponding details in the section provided in the survey which in a way showed the truthfulness of the responses. Due to resources and time constraint set by the online survey builder, the number of respondents analyzed was 40. The number of respondents was thought to be acceptable given that it was a preliminary effort.

Since it was an online survey, the authors have taken few precautions. Invitation for the survey was done through Malaysian ergonomic and automotive related forums in the internet (mentioned in the Acknowledgment) as well as through emails. Regarding the forums website, it requires registered users to login and only members frequent the websites. Further, the survey was supported by the website administrator who has helped distribute the surveys in the website. In addition, the invitation note stated the objective of the survey and welcome only Malaysian drivers to respond. The survey builder has a way to trace and reject more than one feedback from the same subject hence reduces the possibility that a subject responded more than once.

The four sections in the survey took about 14 –18 minutes to complete. The sections were divided according to the different categories and discomfort factors in question, Section A; driving experience, Section B; noise and vibration, Section C; seat discomfort and Section D; personal information.

There are debates in the literatures regarding the appropriate type of scale for discomfort study; uni-dimensional or bipolar and Likert scale or continuous scale [3, 6, 11, 13, 15]. The 5-points one dimension Likert scale was used in this study as a compromise between the need to gather adequate information and the length of questionnaire (the number of pages).

Section A asked about respondents' driving experience and the vehicle and road type that they mostly used. From Section B, perceptions on noise and vibration discomfort were gathered; the discomfort factors were divided into idle and accelerating as shown in Figure 1. Idle was defined as the engine is running but the vehicle is stationary and accelerating is when the engine is running and the vehicle is accelerating. The items selected in this section were thought to affect a driver when he/she is driving, which some were suggested in the literature [6]. In addition, the level of importance of certain characteristics that a vehicle should have was also asked. It was also in matrix form which consists of six items; drive quietness, driving comfort (minimum vibration), driver seat comfort, exterior styling, interior styling and engine power.

Discomfort factors	Idle					Accelerating				
Floor vibration	①	②	③	④	⑤	①	②	③	④	⑤
Steering vibration	①	②	③	④	⑤	①	②	③	④	⑤
Pedal vibration	①	②	③	④	⑤	①	②	③	④	⑤
Seat vibration	①	②	③	④	⑤	①	②	③	④	⑤
Interior noise	①	②	③	④	⑤	①	②	③	④	⑤
Wind/outside noise	①	②	③	④	⑤	①	②	③	④	⑤
Engine noise	①	②	③	④	⑤	①	②	③	④	⑤
Tire noise (accelerating)	①	②	③	④	⑤	①	②	③	④	⑤
Exhaust noise	①	②	③	④	⑤	①	②	③	④	⑤

Figure 1 Items in noise and vibration section from the questionnaire

From Section C, respondents were asked to circle any areas of body parts where they feel discomfort or pain during or after driving on a Nordic body diagram as depicted in Figure 2. Nordic body diagram or a body map is usually found in seat study [4, 7, 17, 18]. As shown in Figure 3, the respondents were required to tick the degree of discomfort that they experienced on fourteen body parts. In addition, they were asked about problem/s that they anticipate with their driver's seat.

The final section collected personal information such as gender, height, weight and monthly salary of respondent. Personal information was asked at the end as suggested in the literature [16].

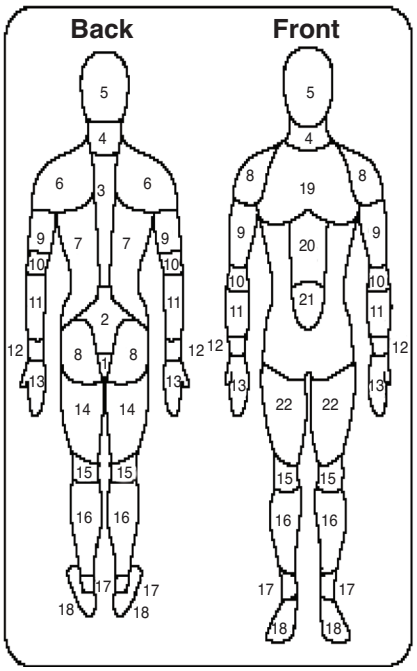

Figure 2 Nordic body diagram

Seat Characteristics	①	②	③	④	⑤
Lower Back	☐	☐	☐	☐	☐
Upper Back	☐	☐	☐	☐	☐
Neck	☐	☐	☐	☐	☐
Hands and Wrist	☐	☐	☐	☐	☐
Shoulders	☐	☐	☐	☐	☐
Upper Arms	☐	☐	☐	☐	☐
Elbow and Foream	☐	☐	☐	☐	☐
Stomach	☐	☐	☐	☐	☐
Chest	☐	☐	☐	☐	☐
Upper Legs	☐	☐	☐	☐	☐
Knees	☐	☐	☐	☐	☐
Lower Legs	☐	☐	☐	☐	☐
Ankles	☐	☐	☐	☐	☐
Feat	☐	☐	☐	☐	☐

Figure 3 Items in question 6 of the questionnaire

3.0 RESULTS

Response from Section A shows that better and/or more expensive cars that are associated with comfort were owned by respondents of 30 years of age and above. However, a respondent earning RM5001–RM10,000 a month (approximately equivalent to USD1535–USD3070 per month) does not necessarily owned better and/or more expensive cars. The majority 73% of respondents used Malaysian made vehicles (Proton, Perodua, Naza and Inokom). About 90% used highway and smooth urban road daily and only 3% had to use the bumpy suburban daily. Only respondents with car manufactured from 1990 and above were analyzed which was also a reason for the limited 40 respondents. Table 1 summarizes the general details of the subjects' driving experiences. A definition of 'professional' driver was annotated in the questionnaire as a driver who is in the vehicle at least four hours because of his/her nature of work. Only 28% were professional drivers,

33% non-professionals and another 40% did not mention the duration and frequency of their daily driving.

Table 1 Summary data for 40 respondents

	N	Age (yrs) (mean ±*SD*)	Driving experience (years)					
			<2	<5	5–10	11–15	>15	null
Total respondents Subgroups	40	31.50±1.23 (n = 39)	2	3	15	9	10	1
Non-professionals	13	32.00±1.66 (n = 12)	2	-	7	1	2	1
Professionals	11	29.70±1.62	-	2	2	5	2	-
Unstated	16	32.70±3.10 (n = 15)	-	-	6	3	6	1
Men non-professionals	4	27.00±1.47	1	-	2	1	-	-
Women non-professionals	9	35.00±1.86	1	-	5	-	3	-
Men professionals	7	30.67±2.65	-	2	-	4	1	-
Women professionals	4	28.60±1.83	-	-	2	2	-	-
Men unstated	9	36.25±2.91	-	1	3	2	3	-
Women unstated	7	32.40±1.76 (n = 6)	-	-	3	1	2	1

	Height (mean±SD)	Weight (mean±SD)
Men	162.2±9.18	73.56±3.67
Women	148.5±7.27	59.86±2.34

Null/unstated = missing data/no answer was given

3.1 Noise and Vibration Discomfort

Figure 4 shows the result for the degree of discomfort that is caused by the seventeen factors given in Section B. Five factors show higher value in slight discomfort (legend SD) than no discomfort (legend ND). The majority reported no discomfort with almost all factors listed. Table 2 shows that slight discomfort response has the highest percentage in terms of discomfort hence are discussed further. Further details on the five factors are shown in Table 3 according to gender of the respondents (slight discomfort labeled as SD).

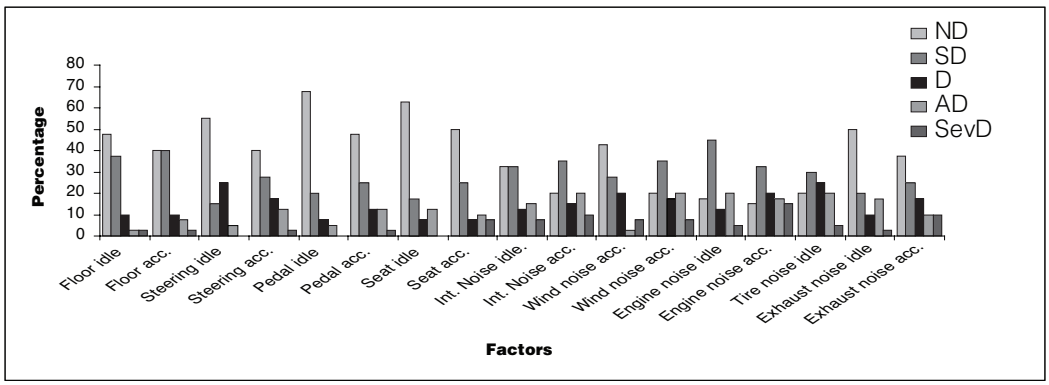

Figure 4 Response for degree of discomfort caused by 17 given factors

Table 2 Response for question degree of discomfort caused by noise and vibration

Level of discomfort	Response percentage (%)
No discomfort (ND)	39.1
Slight discomfort (SD)	28.8
Discomfort (D)	14.6
A lot of discomfort (AD)	12.4
Severe discomfort (SevD)	5.15
Total	100

Table 3 Drivers' slight discomfort perception on five factors

		Interior noise accelerating	Wind noise accelerating	Engine noise idle	Engine noise accelerating	Tire noise accelerating
		SD	SD	SD	SD	SD
gender	men	23%	18%	30%	18%	13%
	women	13%	18%	15%	15%	18%
Total		36%	36%	45%	33%	31%

* SD = Slight Discomfort

Figure 5 depicts that women had reported significantly (ANOVA single factor p-value < 0.01) more discomfort than men at seven out of seventeen factors. Women's slight discomfort responses were more dominant in floor vibration (accelerating), steering vibration (accelerating), pedal vibration (accelerating) and seat vibration (accelerating). The difference of responses between men and women for these four factors are 8–15%. The correlation between these four factors are significantly high (0.58 to 0.86 at 0.01 significant level) as compared to the other factors (less than 0.5 at 0.01 significant level). Men drivers have more problems with factors related to noise than women drivers (ANOVA single factor significant at p-value < 0.01). It is also found their responses are more consistent for all the factors at almost every levels of discomfort.

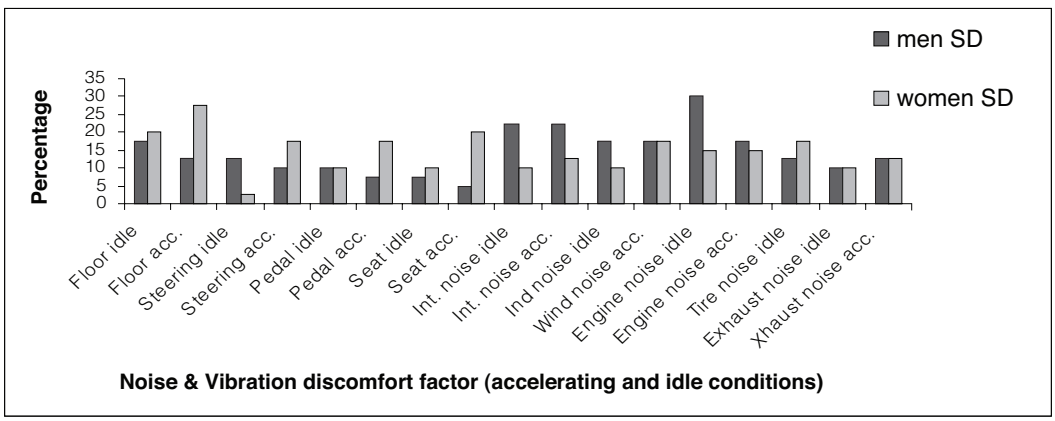

Figure 5 Comparison of men and women drivers for slight discomfort response for noise and vibration discomfort factors

Figure 6 is the result of perception on vehicle characteristic that they think a vehicle should have. Highest responses were for very important instead of compulsory hence is discussed further. The majority (57.5%) thought drive quietness as a very important characteristic of a vehicle followed by drive comfort (50%), seat comfort (42.5%), exterior styling (37.5%), interior styling (27.5%) and engine power (47.5%). Figure 4 however showed that no discomfort (ND) responses were high for vibration related items but not so for noise related items. It shows that the subjects thought that most vehicles have acceptable driving comfort with minimal vibration, however noise is still an obvious problem for them. Figure 7 depicted results for very important (labeled as VI) and compulsory (labeled as Com) according to gender. However, compulsory responses showed both men and women preferred seat comfort over driving comfort and drive quietness.

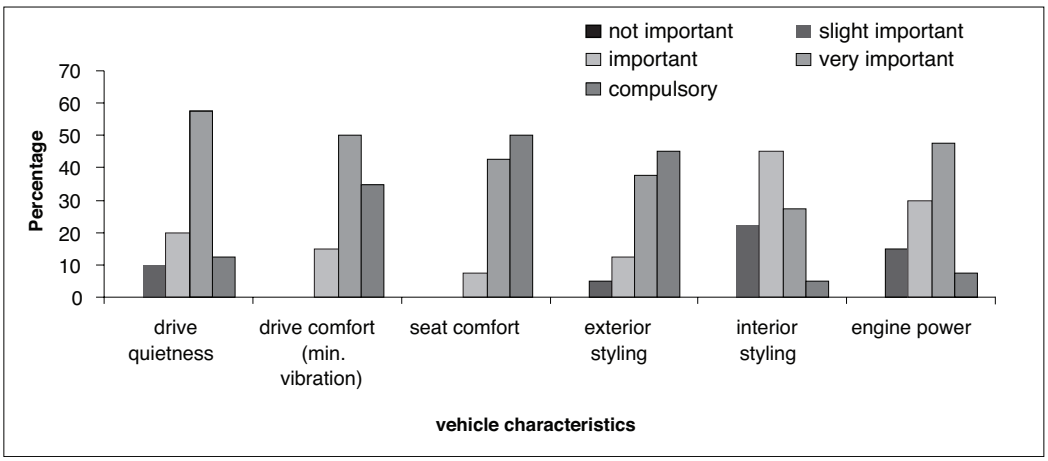

Figure 6 Level of importance of vehicle characteristics as perceived by respondents

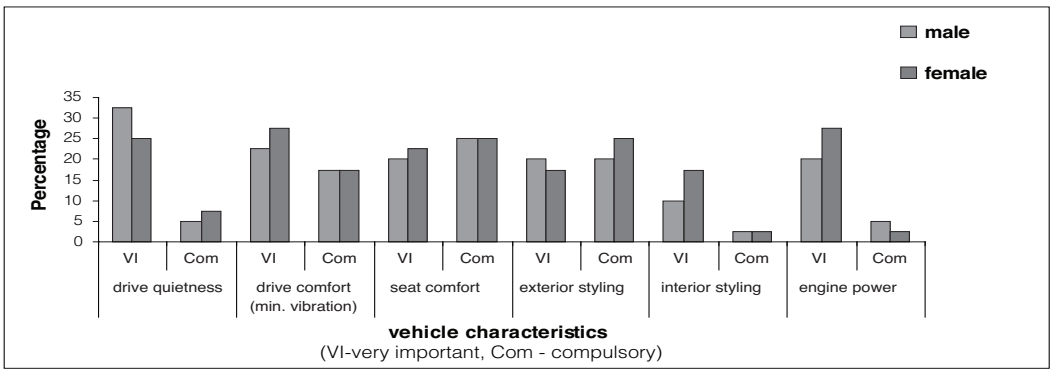

Figure 7 Perception of men and women drivers on the importance of six vehicle characteristics

With respect to driving experiences, 35% of the total responses for slight discomfort for engine noise during idle comes from respondents with more than 5 years driving experience and only 33% from respondents with less than 5 years driving experience. Out of the total responses from respondents aged 30 years old and below, only 26% thought that engine noise during idle was slightly discomfort while majority of them thought it was no discomfort at all. In the case of respondents above 30 years old, 44% thought engine noise during idle was slightly discomfort. However the difference of responses between the two groups of ages was not statistically significant ($p = 0.05$).

3.2 Seat Discomfort

From the standard Nordic body diagram, 60% of the forty responses had experienced discomfort at the upper back; 56% at the neck; and 44% at the low back. Figure 8 presented the degree of discomfort that respondents felt on their fourteen body parts. Table 4 summed up the responses received for seat discomfort section. Seven columns showed higher value in slight discomfort (labeled as SD in Figure 8) than no discomfort (labeled as ND); lower back (37.5%), upper back (42.5%), neck (27.5%), shoulders (35%), lower legs (37.5%), ankles (35%) and feet (37.5%).

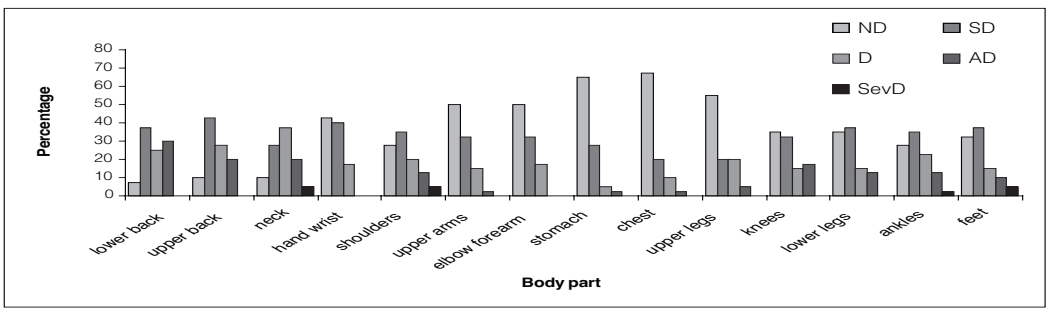

Figure 8 Response for degree of discomfort at fourteen body parts

Table 4 Response percentages for degree of discomfort felt on fourteen body parts

Level of discomfort	Response percentage (%)
No discomfort	36.8
Slight discomfort	32.7
Discomfort	18.8
A lot of discomfort	10.5
Severe discomfort	1.25
Total	100

Figure 9 showed that women had reported more discomfort than men at six out of fourteen body parts and vice versa, two body parts were rated the same. Women responses of slight discomfort were more dominant at hands and wrist, upper arms and elbow and forearm while men at upper back, neck, shoulders, lower legs, ankles and feet. The correlation between the body parts and anthropometry factors such as height and weight is significantly high (0.58 to 0.86 at 0.01 significant level) as compared to the other factors like driving experience and road type (less than 0.5 at 0.01 significant level).

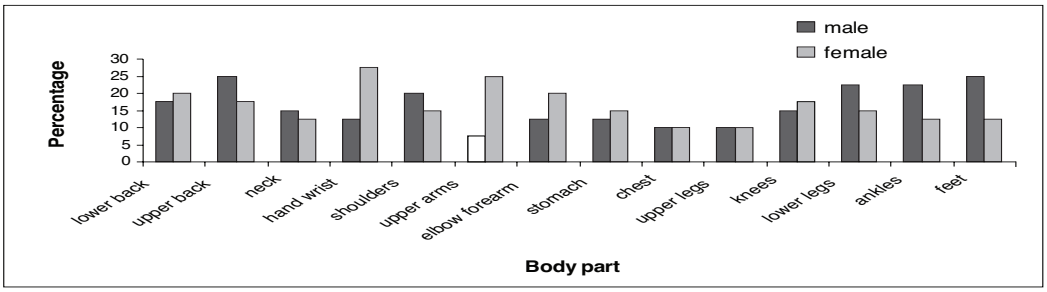

Figure 9 Comparison of men and women drivers for slight discomfort response

However, the overall differences between men and women discomforts mentioned above were not significant. Nevertheless, when analyzed locally, upper arms and elbow and forearms showed that women significantly feel more discomfort than men (p-value = 0.05) while at lower legs, ankles and feet men feel significantly more discomfort than women (p-value < 0.05).

Figure 10 depicted the result of problems that drivers anticipated with their vehicle seat in which the difference between men and women drivers were not significant. Three problems that received high responses were highlighted in Table 5; seat contour, lack of supports and improper location of supports. Referring to Figure 8, seat contour and lack of seat back as well as seat pan supports could introduce discomfort and pain to lower back, upper back, neck, shoulders, lower legs, ankles and feet. The seat problems are related to seat profile and supports which was also the findings of J. D. Power and associates APEAL survey [12]. Their findings suggest that driver's back support has the greatest effect to seat comfort and fatigue.

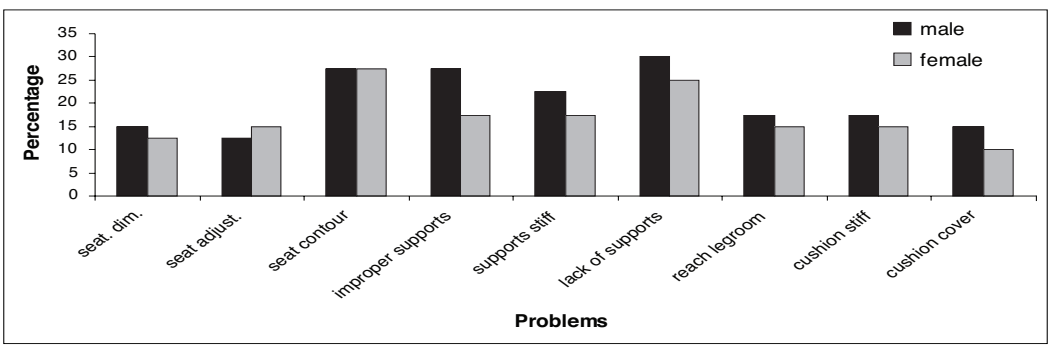

Figure 10 Comparison of men and women responses on driver seat problems

Table 5 Perception of men and women drivers on 3 seat problems suggested in the questionnaire

Seat problems		Seat Contour	Improper location of supports	Lack of supports
gender	male	61%	66%	61%
	female	50%	45%	31%

4.0 DISCUSSION

The majority of the respondents perceive no discomfort with all three factors investigated. The second highest responses for all sections were slight discomfort, which is in line with previous findings from literatures as mentioned earlier. Hence, for all the discussion, slight discomfort results were elaborated further.

From Figure 4 it is shown that floor accelerating and engine noise idle received the highest slight discomfort response (both 40%). It shows that floor vibration and engine noise are among the two most important aspects that need to be addressed, at least for Malaysian vehicle manufacturers mentioned earlier. Based on Figure 5, no significant differences can be shown between responses for accelerating condition and idle condition ($p = 0.05$), although it was proven differently in pilot test that noise and vibration have more effects during idle than in accelerating condition. A possible explanation is that the definition for idle and accelerating annotated in the questionnaire might be overlooked by subjects and they interpreted the terms differently or they need further clarification regarding the terms. The pilot studies were carried out using emails and paper-based questionnaire. Hence, respondents have the means to interact with the authors for clarification and explanation for any uncertainties, in which some of the respondents did (mostly face to face). However, the online-based in the actual survey were truly self-reported type of survey. Although the authors had welcomed any questions or suggestions from the explanatory note, none did so.

It is shown that women drivers slight discomfort responses were higher for vibration related discomforts while men drivers for noise. Similarly it was shown in other survey on a particular type of vehicle; hybrid bus. It reveals female passengers were more likely to mention the smooth ride, while male passengers were more likely to mention the low noise level [19]. As depicted in Figure 5, women drivers were found to be more discomfort than men in areas related to vibration which is transmitted through floor, steering, pedal and seat. A comparable conclusion was made by Giacomin and

Gnanasekaran [6] in their study on steering wheel intensity vibration. They have suggested that women drivers reported more discomfort than men in at least 7 of 28 conditions related to vibration that they had investigated. It is with the assumption that Malaysian women drivers are physically smaller and as such they are more affected to vibrations during driving. Meanwhile, men drivers are well-suited to the seat and their body masses are more tolerable to the vibration. This also suggests that the just noticeable difference level for vibration of the two genders may vary. Regarding noise related discomforts, men are more enthusiastic and passionate towards vehicle. This could be a substantial reason for their sensitivity to the noise related discomforts (refer Figure 5).

No significant differences can be shown between gender regarding seat discomfort ($p = 0.05$). However, local body part analysis (instead of overall discomfort) showed significant difference between genders. Women felt significantly more discomfort than men at the arms area and men felt significantly more discomfort at the lower part of the body (legs to feet). The significant correlation with anthropometrical factor can be a possible explanation especially the heights. Shorter arms require extended arms position for women and longer legs but narrow leg rooms resulted in awkward legs position. However, driving duration and sitting posture could also be the discomfort contributor [7].

It is concluded that based on Figure 8 and Figure 9, the initial hypothesis that claimed the lumbar area is the most discomfort area of the body should be modified. The findings did not fully support the hypothesis. Instead, responses were higher for discomfort felt at the upper back of the body, especially for men although not significantly different from response for the lower back. This is always the debate in many studies regarding gender differences [7, 20].

Some respondents commented that the price of the vehicle is a trade to comfort. Most respondents drive medium-priced Malaysian made car where the seat is not designed well or ergonomically to support the body comfortably. All the Malaysian made cars can be manually adjusted for seat angle and seat height from floor. It is important to note that seat accommodation from 5^{th} percentile female to 95^{th} percentile male is highly depended on seat adjustment range.

However, this conclusion is limited to this survey since 28% of the respondents drive four hours or more daily and the other 33% drive less than that at least 2 times daily. Hence frequency and duration may be the other factor that may cause the discomfort responses. In addition, it was an online survey and respondents were not in a controlled set-up, the effects of interactions of all three factors; noise, vibration, seat system, may have affected the different perceptions of discomfort [9, 21].

5.0 CONCLUSIONS

An online-based questionnaire survey was conducted to gather information regarding driving discomfort of Malaysian passengers' vehicle driver. Duration is thought to be an important variable to be considered in future objective and subjective measurements. Although both men and women felt discomforts caused by their car seats, noise and vibration, the discomfort level and cause of the discomforts varies for each gender.

The numbers valid of respondents were only 40 due to time and resources limitation. Nevertheless, since the results are in-line with previous literatures, it can be considered a worthy preliminary study. The differences of age and gender role in their perspective of driving discomforts can only be shown in percentage and they are not statistically significant.

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