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Applying Subjective Measures to Evaluate Sitting Discomfort: Pertinent Research and Recent Developments

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Abstract – *One of the key considerations when sitting particularly for a long period of time, either in the office chair or car seat is comfort. Studies have revealed a high number of reports regarding discomfort and musculoskeletal disorders while sitting in a fixed position. The main objective of this study is to review past and present subjective assessment in published studies in the area of sitting discomfort and find the gap between each study to be applied in future studies. Fifty relevant studies were identified and chosen from electronic databases, dating as far back as 1969. "Seat", "chair", "sit", "comfort", "discomfort" and "assessment" were the keyword search terms for this paper. Past studies demonstrated numerous purposes and techniques of analysing sitting discomfort. They provide better understanding for both researchers and the industry to deal with sitting discomfort issues. Various assessment methods have also been applied in the previous studies. However, they are still areas found in past studies that need to be investigated. Therefore, it is proposed that another assessment is performed to analyse sitting discomfort, by exploring issues derived from this review.*

Keywords: Seat, chair, sit, comfort, discomfort, assessment

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1.0 INTRODUCTION

Many of us spend most of our days in the sitting position, whether at work, home, while driving and during outings. In addition, it is easier to work while sitting compared to standing. However, continuous sitting brings many disadvantages as well as potential long-term effects. Although sitting requires less muscle work than standing, it still causes physical fatigue because the body needs to adjust to the sitting posture within certain periods of time,

particularly in static seating posture (Andersson, 1980; Althoff et al., 1992; Rohlmann et al., 2001; Wilke et al., 1999; Graf et. Al., 1995; NIOSH, 1997, Lueder, 2004). In fact, Graf et al. (1993, 1995) reported that various discomfort and chronic disorders were detected among workers who sit in fixed postures.

1.1 Subjective Measures in Evaluating Sitting Discomfort

Subjective assessment of subjects is the only way to explore subject preferences and detect changes in comfort and pain (Vergara & Page, 2002). There are various subjective methods used in previous studies, but this paper will only focus on a few methods.

1.1.1 Body mapping and seat mapping

Tan et al. (2008) mentioned that body mapping technique is one of the most common subjective measures. A respondent is required to rate the discomfort on certain body areas according to a given scale. In addition, seat mapping is another subjective method, whereby a seat is divided into different areas. The subject is then asked to provide a rating based on a given scale. Overall, both mapping techniques have quite similar approach.

1.1.2 Checklist

A checklist is another common subjective evaluation tools used in the comfort study. Ordinarily, the respondents are required to respond to a list of statements and rate them according to a particular scale, either dichotomous scale, continuous scale or Likert scale.

1.1.3 Comfort rating scale

There are some important guidelines to be considered when using this tool. As quoted by Shen and Parsons (1997), Pitrella and Kippler (1988) had summarized 14 rating scale design principles, which underline the use of: (1) continuous scales rather than category scale formats; (2) both verbal descriptors and numbers at scale points; (3) descriptors at all major scale markings; (4) horizontal rather than vertical scale formats; (5) either extreme or no descriptors at end points; (6) short and precise descriptors; (7) empirically determined rank-ordered descriptors; (8) equidistant descriptors; (9) psychologically scaled descriptors; (10) positive numbers only; (11) desirable qualities increase to the right; (12) descriptors free of evaluation demands and biases; (13) 11 or more scale points as available descriptors permit; as well as (14) minimized subject workload with appropriate aids. In the past, local discomfort ratings (LDR) have been used to measure sitting discomfort of a subject. Normally, the LDR scale is rated on a scale such as 1 to 10 or -10 to 10.

1.1.4 Questionnaires

A questionnaire is a research instrument consisting a series of questions to gather specific information from subjects. A researcher is required to ask the right questions and validate the questionnaire with a panel of experts before distributing it to respondents.

Aside from all these common methods, there are other subjective methods used in recent studies. Hence, this paper will encompass numerous methods and their application based on past studies. The purposes of this study is to observe existing and present subjective assessments in recent published studies related to sitting discomfort and to find the gap between each study for future research.

2.0 METHODOLOGY

This paper presents a review of recent published studies related to assessment of sitting discomfort. A list of articles in the English language was compiled through Science Direct and Google Scholar websites. “Seat”, “chair”, “sit”, “comfort”, “discomfort” and “assessment” were the keyword search terms for this paper. In addition, a secondary search was performed using a bibliography of retrieved articles in order to support the research scope.

3.0 RESULTS AND DISCUSSION

Substantial research has been performed to evaluate sitting discomfort. Table 1 shows a review of fifty published studies. Based on this review, a majority of the past studies used multiple assessment tools to evaluate sitting discomfort. Hence, a correlation between multiple variables or parameters and relationship between each method can be observed.

3.1 Single Subjective Assessment

Subjective assessment is quicker, cheaper and simpler method to use compared to objective measures (Johns, 2014; Kowalski et al., 2012). Porter and Sharp (1984) studied Body Map Discomfort (BMD) by using five-point scale ratings after 15, 45, 75, 105 and 135 minutes of sitting. A video monitor was used to reduce boredom and ensure that the respondent constantly focus on one direction for the whole time. Analysis of variance was performed on the comfort data, by averaging 14 body areas.

Zhang et al. (1996) performed a study on sitting discomfort factors among office workers by using a questionnaire, consisting of three main sections. Section 1 required the respondents to provide their opinions of current workstation and rank the features commonly considered as essential in the workstation design. Section 2 asked the respondents to describe feelings of comfort and discomfort in a seated workplace, while Section 3 provided a list of comfort and descriptors feelings and the respondents were to rate these descriptors. Figure 1 shows the simplified structure of comfort and discomfort factors after cluster analysis was carried out.

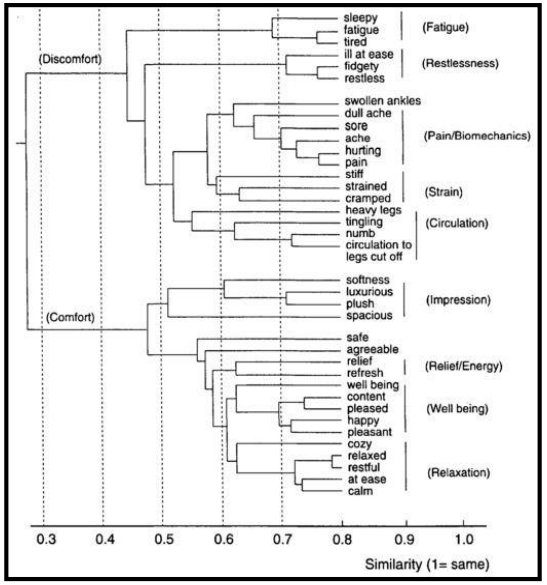

Figure 1: Simplified structure of sitting comfort and discomfort factors based on Zhang et al. (1996)

Table 1: Summary of the recent published studies

Acronyms: B/S M = Body Map/Seat Map, C = Checklist, G = General comfort rating, Q = Questionnaire, O = Others, N = Not mentioned

Note: Other methods (O) are the usage of objective methods tools, such as vibration, pressure and thermal.

Authors	Purpose	B/S M	C	G	Q	O	N	Findings	Comments
Porter & Sharp (1984)	Examine influence of subject variables upon subjective evaluation.	✓						Sitting comfort is not dependent on age, sex, or back pain experience of the respondents.	Subjects adopted normal posture when travel as car passenger in the same type of seat for 2 ¼ hours, but not in the car environment.

Authors	Purpose	B/S M	C	G	Q	O	N	Findings	Comments
Kozawa et al. (1986)	Develop new portable ride comfort meter and new index, known as Vibration Number (VN).						✓	(1) Ride comfort is correlated with acceleration of the seat cushion, seat back, the foot, etc. and influenced by vertical vibration when the ratio of lateral vibration to vertical vibration is smaller; (3) Lateral vibration influence ride comfort when the ratio becomes larger; (4) VN index is with the subjective rating.	Developed new measurement methods to evaluate WBV instead of using ISO 2631.
Shackel, et al. (1969)	Evaluate the seating comfort of upright chairs.	✓	✓	✓		✓		Comfort rating decreased with time. A high correlation between the comfort rating and the direct ranking was found.	10 seats evaluated using 5 different methods but the best method is not mentioned.
Habsburg & Middendorf (1977)	Find a good estimate of seat comfort.	✓	✓	✓				Functional interactions of the seat determined the seat comfort.	Recommend further study to clarify the relationship between seat dimensions and corresponding comfort factors in a dynamic seat evaluation study.
Jianghong & Long (1994)	Evaluate the comfort of a passenger seat for a new type of bus.	✓		✓	✓			(1) Subjects did not feel any sensation of discomfort. (2) Comfort relevant to passenger seats might be viewed as a function of the pattern of physical support.	This study evaluate discomfort in static state. Recommend to further evaluate discomfort in dynamic study.
Bovenzi & Betta (1994)	Study the relationship between WBV dose, perceived postural load and low-back problem (LBP) complaints among the tractor drivers.				✓	✓		(1) LBP found to be higher in the tractor drivers than in the controls. (2) Significant correlation between LBP, vibration dose and postural load. (3) Back accidents and age correlate with LBP.	More epidemiological and exposure data are needed in order to improve the knowledge of the dose-effect relationship between WBV exposure and LBP troubles among professional drivers.
Lee et al. (1993)	Measure seat comfort.			✓		✓		(1) The best 6 seats rated subjectively were the 6 seats with the lowest neck muscle activation. (2) No correlation between pressure data and comfort data.	Contradict findings with another study regarding correlation between pressure and comfort.

Authors	Purpose	B/S M	C	G	Q	O	N	Findings	Comments
Graf et al. (1993)	Measure seat comfort.			✓		✓		The effect of seat shape on the shoulders have significant effect on discomfort.	Compared only two types of seat pan shape.
Wilder et al. (1994)	Measure comfort and muscle fatigue between the seats.			✓		✓		No significant differences in comfort or muscle fatigue between the seats.	More studies should be conducted to prove this findings.
Ng et al. (1995)	Evaluate the effect of an intelligent seat system.			✓		✓		Intelligent System contributed significantly to comfort.	Used microprocessor based interactive seat to assess comfort on standard seat as a baseline.
Thakurta et al. (1995)	Compare subjective assessment of short and long duration sitting comfort.				✓	✓		Correlation between variation of seat pressure and seat comfort.	More studies should be conducted to prove this findings.
Bush & Hubbard (2008)	Compare different type of office chairs.			✓		✓		Significant differences between chairs relative to head and hand motions.	Main focus is on objective assessment. Future study in real working environment for extended periods.
Zhang et al. (1996)	Identify factors related to sitting comfort and discomfort.				✓			The findings have similarities with job satisfaction. The identified factors of sitting comfort and discomfort were indicated in Figure 1.	Further study to test the models found in this study.
Nilsson et al. (1997)	Investigate driving time before fatigue and want to stop driving.		✓					The development of the symptoms of ‘sore feet’, ‘tired eyes’ and ‘feeling drowsy’ were among the good predictors of when they are reaching this critical level of fatigue.	Test in the real highway or road.
Shen & Parsons (1997)	Test the validity and reliability of several rating scales.				✓			The CP-50 is highly reliable and most valid for rating pressure intensity and perceived discomfort and more preferred by respondents.	Test CP-50 for another intensity ratings and subjective constructs.

Authors	Purpose	B/S M	C	G	Q	O	N	Findings	Comments
Fernandez & Poonawala (1998)	Determine the optimum time in an 8 hours work day for evaluating the comfort rating of chairs.			✓				The comfort rating obtained at the end of the third hour of work was not significantly different from that obtained at the end of 8 hours of work.	Test this theory for only 3 hours of work.
Udo et al. (1999)	Compare a fixed seat and a rocking seat.					✓	✓	Rocking condition is preferred as it can reduced LBP and back problem due to its tilting capability.	More time needed to see the discomfort pattern while responding to subjective evaluation.
Goonetilleke & Feizhou (2001)	Propose methodology to determine the optimal seat depth for a target population.		✓					A seat depth of 31–33cm is suitable for the South China region Chinese population in contrast to the ANSI standard of 38–43 cm for the US population.	Five minutes of sitting need to be investigated further whether it is enough for subjective evaluation.
Vergara & Page (2002)	Analyse the causes of lumbar discomfort while sitting on a chair.	✓		✓		✓		The most important factor in the increase of short- term lumbar pain is to adopt lordosis and forward pelvic mean postures.	Investigate changes in variety of posture for the future studies with more respondents.
El Falou et al. (2003)	Study the driver fatigue, discomfort and performance when driving for long duration.	✓		✓	✓	✓		Respondents became uncomfortable during the 150-min trial period. Performance was reduced when subjects were in an uncomfortable seat in the presence of vibration.	There was no evidence of an associated change in SEMG parameters when compared to changes in questionnaire response. Further investigation need to be done.
Philip et al. (2003)	Identify risk factors of performance decrement in automobile drivers.				✓	✓		Age and duration of driving were the main factors associated with decreased performance.	Measure alertness/ sleepiness in this study during driving.
Kolich (2003)	Challenge ergonomics criteria related to anthropometry.				✓			There is discrepancies between published anthropometric accommodation criteria and occupant preferences related to the height of the apex of the lumbar contour, seatback width, cushion length, and cushion width.	The interdependence of various seat comfort aspects should be investigated as part of future research.

Authors	Purpose	B/S M	C	G	Q	O	N	Findings	Comments
Thiffault & Bergeron (2003)	Evaluate the impact of the monotony of roadside to the driver fatigue.				✓	✓		Fatigue is appear when driving in low demanding road environments.	Future research should evaluate the interruption of monotony impacts.
Kolich et al. (2004)	Compare two types of analysis model in determining seat comfort.			✓	✓			The neutral network approach is more superior to predict subjective perceptions of comfort.	Future research should understand the time dependency associated with seat-interface pressure measures.
Hostens & Ramon (2005)	Determine if the muscles would undergo any physiological change due to the repetitive work.				✓	✓		Fatigue were present in the muscles when driving in long hours.	Future studies should involve more muscle measurements in order to see the effect of task distribution changes and the longer periods of driving.
Na et al. (2005)	Investigate the relationships among the pressure distribution and postural changes and discomfort.			✓		✓		High correlation between the body pressure change variables and subjective discomfort ratings.	The proposed new model can be used in the future to evaluate driver discomfort in the actual road.
Fatollahzadeh (2006)	Create and construct a mathematical model to clarify and predict the drivers' comfortable sitting posture and position.	✓		✓	✓			Drivers preferred to sit in the rearmost position and at a rather high level relative to the rest of the available and adjustable area.	The investigation of a complete assessment of comfort in the future should be supplemented with an analysis of how many truck drivers are satisfied with the comfort in the end.
Kong (2006)	Study the static and dynamic characteristics of a bus passenger seat for comfort.	✓		✓		✓		Passenger posture, size and road conditions affected the pressure distribution and SEAT data. A proposed seat structure with spring and damper properties was used and proved to be more effective in achieving seat vibration comfort.	Improve the seat parameters and compare with the previous result.

Authors	Purpose	B/S M	C	G	Q	O	N	Findings	Comments
Cengiz & Babalik (2007)	Evaluate thermal comfort in an extended road trial for three cover materials, velvet, jacquard and micro fibre.				✓	✓		Small difference in respondent feedback on thermal sensation between the three seats. All seat cover materials have the same degree of thermal comfort. On the road the participants feel warmer around their waist than any other area of the body.	More experiment time with more participants in the future will be better for thermal comfort determination.
Newell & Mansfield (2008)	Investigate the influence of sitting in different working postures on the reaction time and perceived workload of subjects exposed to whole-body vibration.					✓		(1) Twisted posture can increase workload demands of simple tasks (2) Armrest usage as a support when evaluating hazards associated with vibrating machinery, may improve performance and reduce the workload demand experienced by operators.	Used older age subjects for next studies and investigate the use of joystick-type controls and the differences between mounted to the seat and mounted to the floor.
Solaz et al. (2006)	Evaluate the static comfort evolution of users while seated on second row van seats by means of principal component analysis of functional data and a set of comfort evolution patterns.	✓		✓				Static comfort data can be transferred to analyse discomfort data from real vehicle tests or simulation in dynamic platforms.	Focus on functional data analysis.
Tsutsumi et al. (2007)	Evaluate the car cabin environment on the driver's comfort and fatigue.			✓				(1) Performance decreased when break up time (BUT) of the respondent's eye gets shorter due to indoor environment. (2) BUT at low humidity was shorter than at high humidity. (3) No difference between eye dryness sensation and visual fatigue.	Car cabin found to affect driver's comfort, performance and fatigue.

Authors	Purpose	B/S M	C	G	Q	O	N	Findings	Comments
Zenk et al. (2007)	Identify a close connection between the seat pressure and the human discomfort.	✓		✓		✓		The seat position with the pressure distribution corresponding to the most comfortable posture the pressure in the intervertebral disc is lowest.	Identification of a close relationship between the pressure on the seat and the discomfort felt by the person sitting.
Parakket et al (2006)	Develop objective methods for determining and predicting human tolerance of prolonged sitting in various seat cushions.			✓		✓		Peak seated pressures ranged from 1.22 - 3.22 psi. Muscular fatigue increased throughout the eight hours regardless of cushion. Subjective comfort levels declined over the eight hours. Correlation between subjective measures and objective parameters for the static cushions.	These results will be used to develop cushion design guidelines, both to prevent deep vein thrombosis and to promote comfort for long-duration use.
Cengiz & Babalik (2009)	Investigate the thermal comfort effects of ramie blended seat cover (RBSC) material on drivers.				✓	✓		High correlation between subjective and objective measures. Back and waist areas are the most sensitive on the human body. The RBSC was a good balancer at high temperature.	Further studies required to determine the long term effects of seat cover material on thermal comfort.
Deros et al. (2009)	Develop a local vehicle seat discomfort survey that is reliable and valid which could be applied together with objective measurements.			✓	✓			The new survey shown a good correlation between the two surveys by Smith et al. (2006) and Kolich and White (2004). It is more understandable by respondents.	Further test would be pairing the assessment tool with objective measures in both static and dynamic environment to examine the correlation between them.
Groenesteijn et al. (2009)	Investigate the influence of chair characteristics on comfort, discomfort, adjustment time and seat interface pressure			✓	✓	✓		No significant differences found for seat design comfort and discomfort, first impression and peak interface pressure.	Investigate in the future about the hypothesis highlighted in this study (refer to discussion section).
Tan et al. (2010)	Examine the seat discomfort and travel time factors for Dutch truck driver seat	✓			✓			The truck seat discomfort is associated with travel duration. Buttock is the most uncomfortable body part for truck driver over time followed by lower back and neck.	Investigate the impact break time in between the driving duration.

Authors	Purpose	B/S M	C	G	Q	O	N	Findings	Comments
Daruis et al. (2010)	Identify the vibration characteristics transmitted to the human in real vehicle conditions or field tests				✓	✓		Steven Power Law equation was able to relate discomfort and whole-body vibration using VDV or RMS significantly. From the objective and subjective evaluation, the exponent β was 1.24 if VDV used and 1.25 if RMS used in the equation.	This test was performed on passenger not a driver.
Kamp (2012)	Define the comfort experience of the new seat with respect to other available seats				✓	✓		Hard seats with rather high side supports are rated sporty, softer seats are rated more luxurious.	Less time required when sitting and that they could not adjust their seat are the study limitations.
Beard & Griffin (2013)	Quantify the extent to which the discomfort caused by lateral oscillation in the range 0.2-1.0 Hz	✓				✓		Low frequency lateral acceleration can cause less discomfort when sitting with a backrest than when sitting on the same seat without a backrest	Different prediction between current standard and findings.
Openshaw (2011)	Predict and quantify office worker seated comfort and discomfort using linear and neural network modelling.				✓	✓		(1) Neural network shows good prediction compared to linear modelling. (2) No significant difference between genders when evaluating comfort/discomfort. (3) Discomfort increased over time and comfort ratings decreased over time.	At least 45 minute comfort testing is needed to understand subjects' comfort/discomfort in a particular office chair.
Lanzotti et al. (2011)	Validate a new statistical index (Weighted Pressure Comfort Loss, WPCL) for seat comfort assessment.			✓	✓	✓		Ordinal logistic regression model (OLR) identifies peak pressure and Pressure Comfort Loss Index (PCL) as the two parameters that are significantly associated to perceived comfort. Comfort degree found to be depended on peak pressure, whereas there is no statistical evidence of dependence on WPCL.	Further studies should consider a refinement of the index so as to take into account variations between neighbouring cells of a pressure map instead of single values. An in-depth study of the most significant anthropometric variables is necessary.

Authors	Purpose	B/S M	C	G	Q	O	N	Findings	Comments
Grabisch et al. (2002)	Modelling the subjective sensation of sitting discomfort.				✓			The proposed methodology is more flexible, and provide information on interaction among variables. The obtained model is easy to interpret due to the clear meaning of the notion of interaction.	Test the proposed modelling in another experiment setup.
Kyung (2008)	Investigate the efficacy of several perceptual ratings in evaluating driver workspace and interface design and clarify relationship between ratings and interface pressure.			✓		✓		Comfort ratings more effective at distinguishing among interface designs, in contrast to the current common practice of using discomfort ratings for designing and evaluating interface designs.	Limitation in this study are; (1) genders were confounded with the stature groups, (2) appearances of car parts could be a confusing factor, (3) historical driving experience with specific vehicle classes could affect subjective responses.
Park et al. (2014)	Analyse the body pressure ratio to evaluate automotive seating comfort.		✓			✓		Pressure ratio for the seat of a compact car is significantly greater than the seat of a sedan car. The subjective comfort was significantly greater for the seat of the sedan car and females than the seat of the compact car and males.	Enlarge sample to include various ages and real drive situation.
Le et al. (2014)	Identify how physiological measures relate to self-reported vehicle seating discomfort.	✓				✓		Subjects taller than 171 cm tended to report discomfort in the lower extremities, respectively. Subjects weighing less than 58 kg tended to report discomfort in the buttocks.	Test the response system along with perceptual influences due to design and in real drive situation.
Mansfield et al. (2015)	Investigating the extent to which reports of discomfort are affected by vibration commencing or ceasing.					✓		Exposure to vibration increases the rate of discomfort onset in comparison to periods of static sitting. When vibration stopped, there was an acute improvement in comfort.	Analyse and test on real road and drive situation.

Authors	Purpose	B/S M	C	G	Q	O	N	Findings	Comments
Mohamad et al. (2016)	Identify the level of awareness for correct and safe driving posture, health implication to their body parts and to propose a suitable car seat for Malaysian drivers.				✓	✓		Driving posture influenced discomfort during driving. Neck, upper and lower back and buttock were the top body parts that experienced discomfort.	Analyse using pressure map for better car seat design.
Soltes et al. (2016)	Proposes a simplified biomechanical model optimized by real world measurements of a passenger in an automobile passing over an obstacle at constant velocity		✓			✓		Good correlation of kinematic data for the head between measured and simulated (optimized) results. Model gives a good indication of the approximate vertical stiffness and damping parameters of a person's neck when driving over an obstacle in an automobile.	Target group were young drivers of average age 24.1 and a normal male body size. To extend subjects on elders and various body size.

A checklist is another well-known subjective method in evaluating sitting discomfort. Nilsson et al. (1997) used this tool to identify actual fatigue symptoms when driving. There were 18 recognized symptoms in this checklist with a four-point Likert Scale (1 = not, 2 = uncertain, 3 = somewhat and 4 = definite). The ratings were verbally made and recorded by the experimenter in a 20-minute interval.

Goonetilleke and Feizhou (2001) had developed a checklist of chair features to determine optimal seat depth for the Chinese population. A respondent was required to rate eight aspects (seat height, seat width, seat depth, seat cushioning, seat stability, seat surface, personal acceptability and overall discomfort) related to a seat by using a five-point semantic differential scale (from 1 = too high/too narrow/too long/too hard/poor/very uncomfortable to 5 = too low/too wide/too short/good/no discomfort), adapted from Drury and Coury (1982) after five minutes of sitting. When the chair was repositioned, a subject was sat down again and the above procedure was repeated for the other four seat depths. The experiment took about 1 and 1.5 hours for each respondent.

Shen & Parsons (1997) examined six scales to be used in the pressure discomfort experiment involving 12 respondents, where four scales were selected from current literatures. The four scales included CP-50 (Scale A), Corlett modified discomfort (Scale B), 8-point discomfort (Scale C) and Borg CR-10 (Scale D). Each scale is explained in details as follows:

i) Scale A: Category Partitioning Scale (CP-50)

As quoted by Ellermeie and Westpha (1991), Heller developed this scale to evaluate pain intensity. The scale was arranged vertically, with a starting point, 0 = no, and five categories; including: 'very slight', 'slight', 'medium', 'severe', and 'very severe'. Each of the categories is further divided into ten scale points. Points above 50 are provided to avoid the ceiling effect on ratings for any extreme intensity (Shen & Parsons 1997).

ii) Scale B: Corlett discomfort scale (CDS)

CDS was basically recognized as Body Part Discomfort (BPD) scale, developed by Corlette and Bishop in 1976 (Shen & Parsons 1997). A five-point scale (0 = no discomfort to 5 = extreme discomfort) with no graphic was used in BPD. The scale has been widely used in evaluating seat and chair because it is easy to use and requires almost no training for the respondents. There were some changes to the BPD scale, where Thomas et al. (1991) modified it by applying the horizontal scale of 10 cm long. The distance between the marking point and the left end of the BPD scale represented the level of discomfort. The left end of the line was assigned as 1 for "just noticeable" discomfort. If no mark was placed, a zero value was given indicating no pain/discomfort (Shen & Parsons 1997).

iii) Scale C: 8-point discomfort scale

As quoted by Shen and Parsons (1997), this scale was used by Yu et al. (1988) and Yu and Keyserling (1989) to rate the pressure stimuli by choosing a number from 0 (no pressure/discomfort) to 7 (extreme pressure/discomfort).

iv) Scale D: Category-Ratio Scale (CR-10) by Borg (1982)

Borg has established different numerical scales for perceived exertion and other physical intensities since 1962. In addition, Borg (1982) developed a 10-point category-ratio scale (CR-10), to rate intensity in wider psychophysical dimensions.

3.2 Combination of Subjective Assessment Tool

Shackel et al. (1969) used a combination of subjective assessment tools to assess sitting comfort of ten chairs. There were General Comfort Rating (GCR), Body Area Comfort Ranking, Chair Feature Checklist (CFCL), Direct Ranking and Body Posture Change Frequency. In GCR, a respondent was instructed to rank order 20 statements by employing 11-point scale (example: I feel completely relaxed, comfortable, cramped, pain etc.), about comfort and select responses which gave the most constant equal interval scale. In CFCL, a respondent was to provide his feedback regarding height, length, width, shape, slope, back support, backrest shape and curvature of selected chair.

Habsburg and Middendorf (1977) employed various subjective and physiological methods such as blood flow and total segmentation accumulation to determine a good estimate of seat comfort of 20 seats. This evaluation took around 15 minutes for each respondent.

3.3 Mixed Approaches: Objective and Subjective Assessment

Combination of different approaches is more favourable to study human discomfort in several areas. Previous studies mentioned that objective measures provide greater reliable reports compared to subjective measures. However, it can be time consuming and sometimes difficult to install the equipment to the respondents (Kowalski et al. 2012). Hence, a combination with subjective measures will help to allay the shortcomings of each approach when conducting the experiment.

i) Vibration and subjective assessment

Bovenzi and Betta (1994) had evaluated 1155 tractor drivers and 220 office workers regarding whole body vibration (WBV) and postural stress. A standardized questionnaire was used in this study to obtain information about low back (LB) symptoms, as well as work and individual related risk factors. Different terms of LB symptoms were used in the questionnaire, as indicated in Table 2. Vibration measurements were performed on the selected respondents. Vibration magnitude and duration of exposure were used to calculate a vibration dose for each tractor driver.

Table 2: Definition of different LB symptoms in questionnaires

Term	Definition
Back pain	Ache, pain or stiffness in the back during lifetime.
LBP	Ache, pain or stiffness in the back during lifetime Ache, pain or stiffness in the lower part of the back during lifetime, or within the previous 12 months or 1 month.
Transient LBP	Recurring episodes of low-back pain of short duration (<14 days) in the past and the previous 12 months.
Chronic LBP	Daily occurrence of low-back pain or several episodes of low-back pain lasting more than 30 days in the past and the previous 12 months.
Sciatic pain	Lifetime experience of radiating pain in one or both legs.
Acute pain	Lifetime experience of sudden attack of low- back pain producing abnormal or locked posture of the back.
Treated pain	Low-back pain treated with anti- inflammatory drugs or physical therapy in the previous 12 months.
Sick leave	Low-back pain causing sick-leave more than 14 days in the previous 12 months.
Disc protrusion	Protrusion of lumbar intervertebral disc identified by clinical and radiological procedures.

ii) Thermal and subjective assessment

Cengiz and Babalik (2009; 2007) investigated the thermal comfort effects of different seat materials, ramie blended, velvet, jacquard and micro fibre during different road trials. In both studies, measurement on respondents' skin temperatures and skin wetness were performed and recorded in computers. In addition, a respondent was required to respond based on the questionnaire survey after each session.

iii) Electromyography and subjective assessment

Lee et al. (1993) used 16 car seats with various foam thickness and hardness to measure seat comfort and discomfort. General and local comfort/discomfort with ten-point scale was used with the combination of electromyography (EMG) measure and pressure map distribution. For EMG, investigation was performed on the neck, shoulder, back, upper leg, and lower leg muscle activation.

Graf et al. (1993), on the other hand, carried out a study to determine the presence of discomfort on standard and modified shapes of seat pan by using EMG and local discomfort rating. In addition, Wilder et al. (1994) also used quite a similar method in their study. However, a visual analogue scale was used to rate comfort/discomfort level when sitting on two types of truck seats with steel spring or gas spring.

El Falou et al. (2003) performed a study on two types of car seat both with and without vibration among 11 subjects by using EMG, performance task, and a questionnaire consisting of 36 body zones. A respondent was to rate the local discomfort based on 10-point scale (0 = no discomfort to 10 = unbearable) and asked general questions on the evolution of discomfort after the experiment.

Hostens and Ramon (2005) conducted a one hour driving test in a simulator by using EMG and questionnaire form. All the respondents were required to position their seat that provide good reach ability to the pedals and steering wheel, but the angle setting of the seat back and pan must be at 110^{o}. The respondents were asked about their fatigue status in general and possible pain spots using a questionnaire before and after the test.

iv) Pressure distribution and subjective assessment

Several studies have also combined subjective assessment tools such as comfort rating with the pressure distribution data. As mentioned by Gefen (2009), past studies showed that there is significant correlation between pressure distribution data and seat comfort rating. Ng et al. (1994) conducted another study with the same approach by developing an intelligent seat system based on the pressure data adjustment on the seat. Subjective comfort ratings (from 1 = very poor to 10 = very good) and anthropometric measurements were also carried out in this study when 20 respondents were required to simulate driving position in a seat buck. Thakurta et al. (1995) compared subjective assessment of short and long driving on 80-mile highway. Thirty-six respondents were evaluated in five small cars by using comfort assessment questionnaire and the pressure distribution was mapped before and after driving.

Bush and Hubbard (2008) conducted a study combining pressure mapping system and motion system with a subjective assessment tool. In order to evaluate a chair preference, the respondents were required to rank all the chairs based on six statements (overall preference, appearance, armrests condition, ease of adjustments, comfort and how well the chair moved with you from lordosis to kyphosis).

A common apparatus used in previous comfort studies is the simulator. For instance, Na et al. (2005) carried out a simulated driving task for 45 minutes. Newly defined dynamic body pressure distribution variables were proposed in this study, and the relationship between these pressure variables with subjective discomfort ratings were examined. Generally, there are

numerous mixed methodology approaches in evaluating sitting discomfort. This paper describes only a few relevant studies found while performing this review.

4.0 CONCLUSION

Discomfort is a subjective experience which can result from a combination of physiological and psychological processes. The literature review of various studies related to sitting discomfort research shows that a combination of objective and subjective measurement is the most common method for evaluating sitting discomfort. Comfort rating is the most popular subjective assessment tool to gather personal perception from respondents in past studies. Nevertheless, this review manages to highlight numerous concerns based on each study as a reference for future research, either in terms of methodology procedures and implementation or consistency of the findings. Hopefully this review can assist researchers, academicians, and industry players to better examine the issue of sitting discomfort in the future.

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