Repeatability of a Checklist for Evaluating Cab Design Characteristics of Heavy Mobile Equipment

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Risk factors associated with the development of musculoskeletal discomfort and disorders during the operation of heavy mobile equipment include whole-body vibration and awkward and sustained joint postures of the shoulders, neck, and trunk. Cab design may influence awkward postures of the joints, and task duration may influence duration of exposure to awkward and static postures and whole-body vibration. To reduce exposure to risk factors related to the interface between cab design and task, it may be necessary for manufacturers to address cab design. This study assessed the repeatability of a cab design checklist developed to evaluate various design characteristics that can influence exposure to risk factors for musculoskeletal discomfort. The ability of the cab design checklist to identify posture-related deficiencies of design was also assessed. The checklist was used by two administrators across 10 pieces of heavy construction equipment. Video analysis was performed to quantify postures of the neck, shoulder, and trunk; correlation analysis was used to determine whether specific questions from the checklist were associated with the identification of awkward postures. The repeatability assessment resulted in kappa coefficients ranging from 0.52 to 1.0 (good-to-excellent reproducibility) across each piece of equipment, and an overall kappa coefficient of 0.77 (excellent reproducibility) when considering all equipment together. Results from the correlation analysis showed that shoulder flexion posture was correlated with scores from the cab design checklist. However, results of the cab design checklist were not significantly correlated with shoulder abduction or awkward postures of the neck and trunk. Results suggest that the cab design checklist may be useful for identifying cab design characteristics that need further improvement and for identifying design characteristics that increase shoulder flexion. The strength of the repeatability assessment suggests that outcomes of the cab design checklist administered by different individuals may be consistent, independent of the type of equipment being assessed.

Keywords awkward postures, construction, operating engineers, postural analysis, whole-body vibration

INTRODUCTION

Kittusamy and Buchholz(1) estimated there were 540,000 operators of heavy mobile equipment in the United States and that 90% of these operating engineers (OEs) performed excavating and paving work and operated earthmoving equipment, such as scrapers, dozers, backhoes, and loaders; the remaining 10% were crane operators. Operators of earthmoving equipment historically experience elevated rates of musculoskeletal discomfort and disorders. Zimmerman et al.(2) found that OEs reported that the greatest frequency of symptoms, missed work, and physician visits were related to the low back, neck, and shoulder regions. Tola et al.(3) found that operators of earthmoving machinery reported higher magnitudes of neck and shoulder discomfort than office workers and carpentry construction workers.

Two prominent work-related musculoskeletal disorder (WMSD) risk factors among operators of heavy earthmoving equipment are static sitting and whole-body vibration,(4−6) where long-term exposure to these risk factors has been associated with low back pain, disc degeneration, sciatic pain, and muscle fatigue.(7−9)

Operators of earthmoving equipment are also exposed to awkward joint postures. Zimmerman et al.(2) indicated that operators self-reported job factors that were most problematic: bending and twisting of the back and working in the same position for long periods of time. Tola et al.(3) reported that working in twisted or bent postures increased the occurrence of neck and shoulder symptoms for operators of earthmoving machinery. Kittusamy(6) quantified the duration of time in non-neutral postures for OEs operating earthmoving equipment during digging-related tasks. Using videotape analysis, and depending on the task and equipment studied, the trunk was in non-neutral postures as much as 68% of the operation time, the shoulders were in non-neutral postures as much as 71% of the operation time, and the neck was in non-neutral postures up to 45% of the operation time.

It has been suggested that exposure to WMSD risk factors stems from the interface between the design of the equipment and cab interior (e.g., location of controls, windows, and mirrors)[1,2] and characteristics of the task (e.g., duration of the task, location of the task that dictates the viewing angle).[2,6] Thus, the design of the cab interior may influence awkward postures of the joints, whereas the long duration of the task may influence the static exposure to awkward postures as well as long-term exposure to whole-body vibration.

To reduce long-term exposure to the WMSD risk factors related to the interface between cab design and task, it may be necessary for manufacturers to address the design of the cab.[2] Feedback from equipment evaluations and user comments to the manufacturers are necessary for successful redesign, suggesting there is a need for a reproducible evaluation tool to assess the design of the cab of the equipment.

Kittusamy[10] developed a checklist to evaluate the cab design of mobile construction equipment (Table I). The checklist is a general assessment tool for identifying characteristics of the cab that may affect operator performance and suggest need for improvement. The checklist was drafted on the basis of a literature review and discussion with operators of construction equipment. Subsequently, the draft checklist was pilot tested with input from trainers, operating engineers, and apprentices.[10]

This checklist was designed to be used as an interactive tool between the operator of the equipment and the individual administering the checklist. Approximately half the questions

TABLE I. Cab Design Checklist Questions

	Questions	Yes	No	N/A	Comments
1	Is the seat height adjustable?				
2	Can the seat be adjusted horizontally?				
3	Is the seat set at proper height?				
4	Does the seat have a back support?				
5	Does the seat have a lumbar support?				
6	Are there armrests available?				
7	Are the armrests adjustable?				
8	Are the armrests set at proper height?				
9	Do you feel any vibration from the equipment through the seat?				
10	Do you feel any vibration from the equipment through the floor?				
11	Do you feel any vibration from the equipment through the controls?				
12	Is the seat firmly mounted to the floor of the cab?				
13	Can the seat be tilted backward?				
14	Can the seat swivel?				
15	Is the location of the controls or levers adjustable?				
16	Can you easily reach the levers or controls?				
17	Can you easily operate the levers or controls?				
18	Can you easily reach the pedals?				
19	Can you easily operate the pedals?				
20	Is the cab area large enough (e.g., uncramped area) for you?				
21	Do you have sufficient upward visibility?				
22	Is your view of the operation obstructed (e.g., cab guards, pipes/hoses, etc.)?				
23	Do you feel the cab is noisy?				
24	Can you control the temperature of the cab?				
25	Does the equipment have steps?				
26	Does the equipment have handrails?				
27	Can you easily open/close the cab doors?				
28	Does the equipment have proper means for entering the cab?				
29	Does the equipment have proper means for exiting the cab?				
30	Do you have a good general view of the ground?				
31	Are the cab windows free from distracting reflections?				

Note: Questions are from article by Kittusamy.

ask the operator's opinion (yes/no) on cab design issues such as vibration from the equipment, reaching, and operating the controls, visibility of the task, and the cab area. The remaining questions address cab design characteristics that are more structural in nature, such as seat characteristics (e.g., back and lumbar support, adjustable, tilt capability), armrest characteristics (e.g., are they present, adjustable, etc.), and egress means.

Although the intent of this checklist is to provide manufacturers with feedback on cab design issues that may need to be improved, the checklist has not been assessed for repeatability of responses. In addition, because previous research suggests that cab design may influence postural contributions to musculoskeletal discomfort, it is of interest to determine whether specific sets of questions of this checklist are associated with awkward postures during operation.

The objective of this study was to assess the repeatability of the cab design checklist from the observations of the administrators and responses of the operators to the checklist questions. Also investigated were the potential associations between specific sets of questions of the cab design characteristics and resulting awkward postures of the neck, shoulder, and trunk.

METHODS

Approach

The methodology used for this study consisted of videotaping OEs while they operated different types of heavy mobile equipment, quantification of joint postures through observational techniques, and administration of the cab design checklist by two individuals to assess the repeatability of the checklist.

Subjects

Four OEs volunteered to answer questions from the cab design checklist. The mean age of the OEs was 47 years (standard deviation [SD], 6.4 years) and they had a mean experience of 25 years (SD, 7.1 years).

Study Site

The cab design checklist data were collected over 2 days at the International Union of Operating Engineers training center in Ellensburg, Wash. Weather and soil conditions were dry during data collection days. Cabs of 10 different types of heavy mobile equipment such as excavators, dozers, tower cranes, graders, scrapers, loaders, and dump trucks were assessed (Table II); the operators were videotaped.

TABLE II. Equipment Characteristics

Type of Equipment	Manufacturer	Model
Skidsteer	Bobcat	763
Tower Crane	Liebherr	132HC
Excavator	Hitachi	EX 220
Loader	John Deere	744H
Dozer 1	John Deere	650H
Dump Truck	John Deere	BELL25C
Scraper	International Harvester	431B
Grader	John Deere	772CH
Dozer 2	Caterpillar (CAT)	D8R
Backhoe/Loader	Caterpillar (CAT)	416C

Experimental Procedure

Prior to data collection, the four participating OEs were briefed about the study and provided their informed consent. All data collection was performed by researchers from the National Institute for Occupational Safety and Health–Spokane Research Laboratory, with support from the International Union of Operating Engineers. Detailed data analysis was performed by researchers at Wichita State University.

The cab design checklist was administered by two individuals: one administrator with 2 years' experience in ergonomics, the other with approximately 20 years' experience in ergonomics. One of the administrators read the checklist questions to the equipment operator and then recorded the operator's responses. After answering all the questions, the operator then performed construction tasks that were videotaped for approximately 30 min. After videotaping was completed, the operator returned to the data collection location. The other administrator then read checklist questions to the operator and recorded the responses. The order in which the administrators collected this data was randomized.

Two unsynchronized video cameras were installed in the cabs to capture left and right side views of the OEs. The cameras were turned on as close to simultaneously as possible, and video was collected for approximately 30 min in each piece of equipment. Camera angles were chosen so that joints of interest (i.e., the neck, trunk, and shoulders) were clearly visible. After videotaping, a posture analysis was performed on all subjects for all joints of interest, on all pieces of construction equipment. Then the video analysis process was repeated once more to verify consistency with the first analysis.

To analyze the recorded postures, video analysis software (Multimedia Video Task Analysis [MVTA], NexGen Ergonomics, Montreal) was used. Events (e.g., posture) were discretely and interactively identified by using break points in the video record (identifying the start and end of an event). MVTA produces time study reports that included the duration of each defined event.

Three different joints and their corresponding categories of posture (i.e., high and low exposure) were predefined in the software. While the video played, the analyst pressed the appropriate predefined key, and the software automatically recorded the duration of cycle time and saved it under the corresponding category. During the video analysis, the analysts had the option of stopping or slowing down the video.

Postural Categories

Range of motion of the joints was divided into predetermined postural categories (Figure 1), which were based on the categories identified in the WMSD exposure assessment literature.[6,11–15] Lowe[16] indicated that fewer postural categories resulted in fewer posture exposure misclassifications, increasing the accuracy of the exposure assessment. Thus, two postural categories were used for each joint and plane of interest for the postural assessment.

Exposure categories for neck flexion were 0°–45° (low) and >45° (high), and 0°–20° (low) and >20° (high) for lateral neck bending and neck twisting.[13,14] Postural categories for trunk flexion were 0°–30° (low) and >30° (high), 0°–20° (low) and >20° (high) for lateral trunk bending and trunk twisting.[12,15] Shoulder flexion and abduction postural categories were defined as 0°–60° (low) and >60° (high).[17]

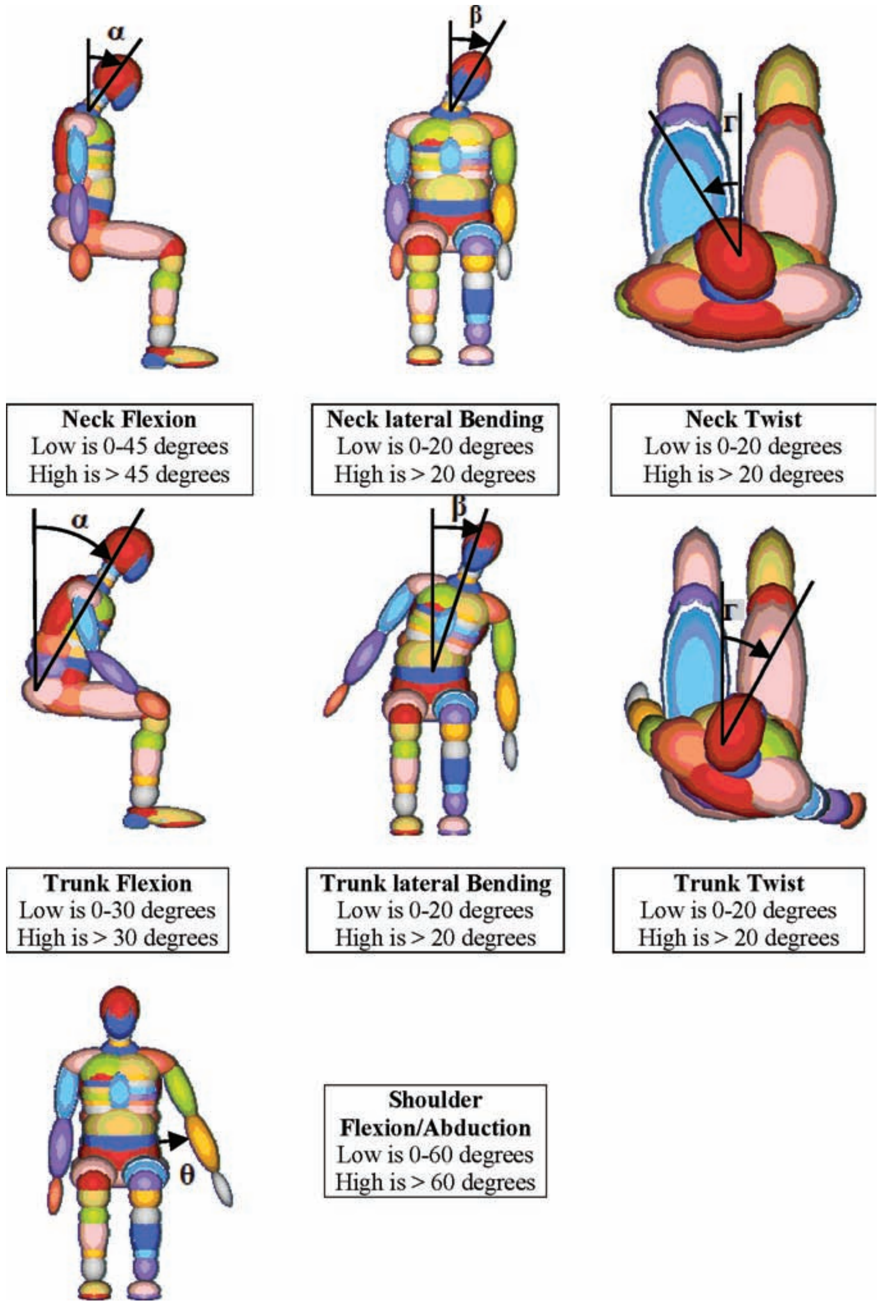

FIGURE 1. Posture categories used to classify neck, trunk, and shoulder postures

Data Analysis

The overall cab design checklist score was determined by using all 31 questions of the cab design checklist. Questions 9, 10, 11, 22, and 23 were negatively phrased so that an affirmative answer meant the same as the other questions in the checklist (a positive response). The percentage of the affirmative answers to all 31 questions was determined. The closer this value was to 100%, the better the design (or acceptability) of the cab. This measure assumes equal weighting for each of the questions, and each question measures a different characteristic that might impact the ergonomics of the cab design.

Joint-specific checklist scores were determined using specific questions about cab design features that could contribute to awkward postures of the neck, trunk, and shoulders. Questions that addressed cab design characteristics that could impact awkward postures of a specific joint were grouped. Ten questions from the cab design checklist were used for the neck postures (Questions 1, 2, 3, 14, 16, 17, 21, 22, 30, and 31). These included questions about seat height and adjustability, which could affect neck posture to see controls or see the work location, and location of controls that may necessitate awkward postures to see the levers.

Fourteen questions were used for the trunk postures (Questions 1, 2, 3, 4, 5, 13, 14, 15, 16, 17, 21, 22, 30, and 31), which included questions about seat height, adjustability, tilt, lumbar support, and lever locations that may result in reaching, bending of the trunk, and view of the work outside the cab. Seven questions were used for the shoulder postures (Questions 1, 2, 3, 14, 15, 16, and 17), which included questions about seat adjustability and lever locations that may result in reaching to operate.

Again, the closer the joint specific cab design checklist score was to 100%, the better the design (or acceptability) of the cab for the specific joint of interest. For assessment purposes, a checklist score at or above 80% was arbitrarily chosen to suggest adequate design or acceptability.

Statistical Analysis

Due to the intended interactive nature for the administration of the cab design checklist, the repeatability assessment is a combination of repeatability: (*a*) for the questions about equipment operation, and (*b*) of the interaction between the administrator and operator in addressing questions regarding cab characteristics that were more structural in nature. Checklist repeatability was assessed by using the kappa coefficient, which was computed using the data collected by two different administrators for all 31 questions, assessing each of the 10 pieces of equipment separately. In addition, the overall repeatability of the cab design checklist was determined by calculating the kappa coefficient for the combination of the 10 pieces of equipment. The kappa values were interpreted using the guidelines by Landis and Koch[18] and a one-tailed test was employed to test the hypothesis $H_0{:}\ \kappa = 0$ vs. $H_1{:}\ \kappa > 0$ setting $\alpha = 0.05$.[19]

To determine whether specific groups of questions of the cab design checklist were capable of identifying cab design features that may be associated with awkward joint postures, the Pearson product moment correlation coefficient was calculated between the duration of each joint in the low postural category and the joint-specific cab design checklist score (i.e., neck, shoulder, trunk) from the 10 pieces of equipment combined. Only the checklist scores from the more experienced administrator were used for this analysis.

RESULTS

Overall Cab Design Checklist Scores

The results of the overall cab design checklist scores for each of the 10 pieces of equipment are shown in Table III. Six of the 10 pieces of equipment had scores greater than 80%, indicating that for 6 pieces of equipment, more than 80% of the 31 checklist questions were answered with an affirmative (or positive) response. The grader had the highest score (90%) and the skidsteer the lowest score (56%), suggesting the grader had a better overall cab design than the skidsteer.

Joint-Specific Cab Design Checklist Scores

Joint-specific cab design checklist scores are shown in Table IV. For the neck and trunk, the majority of the equipment had scores ≥80% (e.g., affirmative answers on the joint-specific questions), whereas only half the equipment had shoulder joint-specific scores ≥80%. The skidsteer and the scraper had joint-specific scores less than 80% for all three joints, suggesting that the design of the cab may influence awkward postures of multiple joints of the operators. Conversely, the excavator, grader, and backhoe/loader had joint-specific checklist scores ≥80% for all three joints, suggesting that cab design characteristics may result in what may be considered nonawkward postures of the neck, trunk, and shoulders.

Joint-Specific Posture Analysis

The type of equipment used by the operators along with the duration (percentage of time) in the low postural category

TABLE III. Overall Cab Design Checklist Scores

Equipment	Overall Score (%)
Skidsteer	56
Tower crane	86
Excavator	81
Loader	74
Dozer 1	76
Dump truck	87
Scraper	61
Grader	90
Dozer 2	81
Backhoe/loader	81

Note: Percentages of affirmative answers as a function of each piece of equipment.

TABLE IV. Joint-Specific Cab Design Checklist Scores

	Joint		
Equipment	**Neck (%)**	**Trunk (%)**	**Shoulder (%)**
Skidsteer	60	54	60
Tower crane	82	69	80
Excavator	82	81	80
Loader	73	80	70
Dozer 1	80	87	70
Dump truck	73	88	80
Scraper	73	75	50
Grader	82	82	90
Dozer 2	82	82	70
Backhoe/loader	91	82	80

Note: Percentages of affirmative answers as a function of individual equipment and body joints.

for neck, trunk, and shoulder joints obtained from postural analysis are shown in Table V. Operators spent at least 90% of the observed operation time in the low postural category for all 10 pieces of equipment for neck flexion, lateral neck bending, trunk flexion and lateral bending, left shoulder flexion (except for the scraper), right shoulder flexion, and left and right shoulder abduction.

Neck twisting and trunk twisting were more prevalent as far as percentage of time spent away from the low postural category. For neck twisting, only the skidsteer resulted in duration above 90% in the low postural category, with a mean across all equipment of 77.1%. Twisting of the trunk was also less prevalent in the low postural category, where the excavator, loader, both dozers, scraper, and grader had durations in the low postural category of less than 90%, with a mean across all equipment of 88.5%.

Cab Design Checklist Repeatability

The kappa coefficients ranged from 0.52 to 1.0 across each piece of equipment, which represents good-to-perfect repeatability of the checklist (Table VI), and all kappa coefficients were significantly greater than zero ($p < 0.001$). The skidsteer, the scraper, and one of the dozers had excellent repeatability; the excavator had perfect agreement; and the rest of the equipment had good repeatability. When considering all 10 pieces of equipment together, the kappa coefficient was 0.77, which indicates excellent repeatability for the cab design checklist across multiple equipment types.

Matching answers to the checklist questions given to both administrators are presented in Table VII. Twenty of the 31 questions (64.5%) had either no mismatches or one mismatched response across the 10 pieces of equipment; 9 of the 31 questions (29%) had two mismatched answers. The questions that had the largest number of mismatched responses were Question 13: Can the backrest be tilted backward? (three mismatched answers) and Question 22: Is your view of the operation obstructed? (four mismatched answers).

Cab Design and Joint Posture Correlation

The correlation assessment between the joint-specific cab design checklist scores (across all 10 pieces of equipment) and the duration of time in the low postural category resulted in no significant correlations (Table VIII). All 10 pieces of construction equipment were large machinery except for the skidsteer, where the cabin was much more cramped than the rest of the equipment. Thus, the correlation between the joint-specific cab design checklist scores and the duration of time in the low postural category were assessed for mobile equipment of similar size (i.e., excluding the skidsteer), which can be found in Table VIII.

Left shoulder flexion was significantly correlated with the joint-specific cab design checklist score for the shoulder ($r = 0.73$; $p = 0.025$), whereas right shoulder flexion approached significance ($r = 0.59$; $p = 0.095$). No other postures were significantly correlated with the joint-specific cab design checklist scores.

DISCUSSION

The operation of mobile construction equipment results in exposure to several risk factors for WMSDs, including whole-body vibration and long duration of sitting that result in static loading on the spine.[1] In addition, the location of the controls, combined with the necessity to be able to see outside the cab in nearly all directions, can result in sustained and repeated awkward postures of the neck, shoulder, and torso. Thus, the design of the cab and the interface with the job requirements influences the exposure to WMSD risk factors.

Intervention strategies to reduce the WMSD risk include decreasing the magnitude and duration of exposure to risk factors, such as vibration and unsupported static sitting. However, to address the awkward postures that can result due to the design of the cab and location of controls, it may be necessary to identify these limitations early in the design stage. Thus, the cab design checklist was developed in an attempt to identify design deficiencies with respect to WMSD risk factors.

It is anticipated that the cab design checklist will be used by multiple administrators as a tool to evaluate multiple pieces of mobile equipment. Because it is likely that different individuals will administer a checklist such as this one, it is important that the checklist produce repeatable results regardless of who is performing the evaluation.

Thus, the major objective of this study was to assess the repeatability of the cab design checklist. Using two checklist administrators, one with many years of experience in ergonomics and heavy construction and one relatively new to the field, the results indicated that the repeatability of the cab design checklist ranged from good to perfect across all 10 pieces of equipment, with an overall kappa coefficient of 0.77 across all the equipment (i.e., excellent agreement). This

TABLE V. Joint-Specific Duration of Time (%) in Low Exposure Category

Equipment	Neck Flexion (<45°)	Neck Bending (<20°)	Neck Twist (<20°)	Trunk Flexion (<30°)	Trunk Lateral Bending (<20°)	Trunk Twist (<20°)	Left Shoulder Flexion (<60°)	Left Shoulder Abduction (<60°)	Right Shoulder Flexion (<60°)	Right Shoulder Abduction (<60°)	Mean (SD)
Skidsteer	100	100	93	100	100	99	100	100	100	100	99.2 (2.2)
Tower crane	99	100	82	100	100	100	100	100	100	91	97.2 (6.0)
Excavator	99	99	84	97	98	79	92	100	100	100	94.8 (7.5)
Loader	98	100	82	98	99	88	100	100	99	100	96.4 (6.2)
Dozer 1	99	100	88	97	98	88	91	99	100	100	96.0 (5.0)
Dump truck	97	95	69	99	99	91	100	99	98	99	94.6 (9.4)
Scraper	95	100	60	99	92	76	65	100	97	100	88.4 (15.5)
Grader	99	99	66	97	95	74	100	100	100	100	93.0 (12.4)
Dozer 2	93	90	68	98	94	92	100	99	100	98	93.2 (9.5)
Backhoe/loader	100	99	79	100	100	98	100	100	100	100	97.6 (6.6)
Mean (SD)	97.9 (2.3)	98.2 (3.3)	77.1 (10.7)	98.5 (1.3)	97.5 (2.8)	88.5 (9.5)	94.8 (11.1)	99.7 (0.5)	99.4 (1.1)	98.8 (2.8)	

checklist thus has the potential to produce reproducible results no matter who is administering the checklist.

The majority of the checklist questions (29 of 31) were consistently answered for both administrators across 80% of the equipment assessed. Question 22 (Is your view of the operation obstructed?) was inconsistently answered for four pieces of equipment. It is possible that the inconsistent response may be related to the tasks that were performed between the time of the first and second administration of the checklist. Question 13 (Can the seat be tilted backward?) was inconsistently answered for three pieces of equipment. Although it is unknown why this was responded to differently three times, it is possible that the operators did not, in fact, know the true ability of the seat, or confused it with another seat function.

Overall, however, the cab design checklist proved to be repeatable, with the majority of the questions eliciting consistent responses. The checklist may have the potential to be used to assess different types of large mobile equipment to provide feedback to manufacturers for improvement in the interface between the task and interior cabin design, with the ultimate goal of reducing exposure to risk factors to WMSDs for the operators of the equipment.

The postural assessment during operation of the various pieces of equipment suggests that twisting of the neck and of the torso are the most frequent awkward postures assumed. This is consistent with findings from previous studies by Zimmerman et al.[2] and Tola et al.[3] Zimmerman et al. reported that OEs felt that working in the same position and bending and twisting the back in an awkward way were the two highest rated job factors perceived as most

TABLE VI. Kappa Coefficients for the Repeatability of the Cab Design Checklist

Equipment	Kappa Coefficient	p-value	Agreement
Skidsteer	0.77	<0.001	Excellent
Tower crane	0.70	<0.001	Good
Excavator	1.00	<0.001	Perfect
Loader	0.69	<0.001	Good
Dozer 1	0.74	<0.001	Good
Dump truck	0.52	<0.001	Good
Scraper	0.87	<0.001	Excellent
Grader	0.53	<0.001	Good
Dozer 2	0.90	<0.001	Excellent
Backhoe/loader	0.71	<0.001	Good
All equipment	0.77	<0.001	Excellent

Note: Coefficients as a function of each piece of construction equipment.

TABLE VII. Correct Matches Between the Two Administrators

	Questions	Yes	No	N/A	Comments	Correct Matches
1	Is the seat height adjustable?					10/10
2	Can the seat be adjusted horizontally?					8/10
3	Is the seat set at proper height?					10/10
4	Does the seat have a back support?					10/10
5	Does the seat have a lumbar support?					8/10
6	Are there armrests available?					10/10
7	Are the armrests adjustable?					8/10
8	Are the armrests set at proper height?					8/10
9	Do you feel any vibration from the equipment through the seat?					8/10
10	Do you feel any vibration from the equipment through the floor?					8/10
11	Do you feel any vibration from the equipment through the controls?					9/10
12	Is the seat firmly mounted to the floor of the cab?					10/10
13	Can the seat be tilted backward?					7/10
14	Can the seat swivel?					10/10
15	Is the location of the controls or levers adjustable?					9/10
16	Can you easily reach the levers or controls?					9/10
17	Can you easily operate the levers or controls?					10/10
18	Can you easily reach the pedals?					10/10
19	Can you easily operate the pedals?					10/10
20	Is the cab area large enough (e.g., uncramped area) for you?					8/10
21	Do you have sufficient upward visibility?					10/10
22	Is your view of the operation obstructed (e.g., cab guards, pipes/hoses, etc.)?					6/10
23	Do you feel the cab is noisy?					8/10
24	Can you control the temperature of the cab?					9/10
25	Does the equipment have steps?					9/10
26	Does the equipment have handrails?					10/10
27	Can you easily open/close the cab doors?					8/10
28	Does the equipment have proper means for entering the cab?					10/10
29	Does the equipment have proper means for exiting the cab?					10/10
30	Do you have a good general view of the ground?					9/10
31	Are the cab windows free from distracting reflections?					10/10

Note: Correct matches across the 10 pieces of equipment.

problematic. Tola et al. reported that working in twisted or bent postures (e.g., neck and shoulders) were predictors of neck and shoulder symptoms of operators of earthmoving machinery.

All other postures were in the low postural category for more than 90% of the observation time (mean of all 10 pieces of equipment), suggesting adequate posture for the individuals observed. The scraper was the piece of equipment that resulted in the lowest percentage of time for postures in the low postural category collectively across all equipment, which was dictated by longer durations in the high awkward postural category for neck twisting, trunk twisting, and left shoulder flexion.

The durations of time in the low postural categories in this study were higher than those reported by Kittusamy,[6] However, Kittusamy quantified posture of the trunk, neck, and shoulders for dynamic digging tasks, which may have required more awkward postures of the joints to see the work location. In addition, the video cameras for Kittusamy were placed outside the cab, which may have resulted in obstructions in the video, whereas the cameras in the present study were placed inside the cab.

The correlation analysis performed between the joint-specific cab design checklist scores and the low exposure posture category values suggested a potential relationship between design characteristics of the cab (e.g., lever and control placement, seat height, and adjustability) and shoulder flexion. Twisting of the arms and shoulders and bending have been noted in studies assessing musculoskeletal discomfort,[2,3] which were related to location of controls. The correlations between the cab design checklist questions related to shoulder posture and duration of shoulder flexion were not significant

TABLE VIII. Correlation Between Joint-Specific Cab Design Checklist Scores and Duration of Time in Low Exposure Category

Cab Design Checklist Joint	Posture	All Equipment (N = 10) Correlation (r)	p-value	All Equipment Except Skidsteer (N = 9) Correlation (r)	p-value
Neck	Neck flexion	0.08	0.80	0.23	0.51
	Neck lateral bending	−0.22	0.50	−0.17	0.64
	Neck twisting	−0.31	0.32	−0.16	0.66
Trunk	Trunk flexion	−0.28	0.43	−0.14	0.72
	Trunk lateral bending	0.02	0.95	0.19	0.63
	Trunk twisting	−0.19	0.60	−0.01	0.98
Shoulder	Shoulder flexion (right)	0.35	0.32	0.59	0.095
	Shoulder flexion (left)	0.52	0.12	0.73	0.025
	Shoulder abduction (right)	0.00	1.00	0.11	0.78
	Shoulder abduction (left)	0.05	0.89	0.23	0.55

when the skidsteer was included in the analysis, whereas these correlations became and approached significance when it was excluded.

It may be that the compact design of the skidsteer, and placement of the video camera that showed a view of the operator, was unlike the operators of other larger equipment that had larger cabs. Overall, for larger mobile construction equipment, questions from the cab design checklist related to seat height and adjustability, and the location of controls in relation to ease of operation, may have the potential to identify cab design characteristics that are consistent with awkward postures of the shoulder, specifically, shoulder flexion.

The results of this study should be considered in light of methodological limitations. First, although the postural categories were based on previous studies and epidemiologic research, the duration in the different joints in the low postural category should be interpreted with caution, as some joints included a large range in the low postural category (e.g., shoulder flexion and abduction from 0° to 60°), and shoulder musculoskeletal problems may arise at shoulder flexion and abduction angles less than 60°.

Also, it is likely that operators reduced the loading on the shoulders at large angles of flexion by resting their arms on the steering wheel at times; however, the confined space in the cabs did not allow a camera field of view large enough to consistently determine this. Second, the categorical postural quantification was based on one observer where the reliability of the postural assessment is not known.

Third, only the responses from one of the checklist administrator's was used for correlation analysis between the postural categories and specific checklist sets of questions related to posture of the neck, shoulder, and trunk. Because the repeatability was good to excellent across the responses of both administrators, this was considered to be a minor limitation. Finally, the accuracy of the off-plane postures such as twist and lateral bending is not known and may be questioned due to the postures not being in the oblique field of view of the video camera. This may be why only the sagittal plane postures of the shoulders resulted in higher correlations with posture specific cab design checklist questions.

CONCLUSION

Operating engineers experience musculoskeletal discomfort at elevated rates to the low back, neck, and shoulders. The risk factors that increase the risk of musculoskeletal discomfort and disorders are related to the design of the task and the design characteristics of the cab of mobile construction equipment. The cab design checklist developed by Kittusamy[10] contains excellent repeatability when used across multiple types of mobile construction equipment. Compared with videotaping and analysis, this checklist is a quick and less costly method to identify potential problems in the cab design. Finally, use of this checklist can provide information that can be used by the operator, supervisor, and equipment manufacturer of mobile equipment to modify cab characteristics that can enhance the overall safety and health of the operators.

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