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Musculoskeletal Load in and Highly Repetitive Actions of Animal Facility Washroom Employees

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Regular work tasks in the washroom of laboratory animal facilities include cleaning of cages and bottles and handling of chow and bedding. These operations largely are carried out by hand. We quantitatively determined the musculoskeletal load on the trunk and upper limbs of washroom employees in an animal facility with a holding capacity of 35,000 rodent cages by using a computer-assisted, quantitative, recording, and long-term analysis (CUELA) system, which volunteers wore during routine work. Parallel video recording allowed exact assignment of each movement of body and limbs to the data recorded by the sensors. For the most part, trunk movements were unassociated with risk of injury. Evaluation of upper limb movements by CUELA indicated elevated burden on shoulder, elbows, and wrists due to the high repetitiveness and range of movements and postures. However, after additional work factors like low effort and the presence of micropauses were taken into account, workers were not at risk for the development of musculoskeletal disorders of the upper limbs. Handling bottles, chow, and bedding and maneuvering trolleys that entailed greater musculoskeletal loads did not yield evidence of overstraining, because the actions typically were executed alternately and were of short duration during daily shifts. The results represent quantitative information on the musculoskeletal load of regular washroom operations in a laboratory animal facility. These data provide the basis for ergonomic redesign of operations and implementation of automation for highly repetitive movements.

Abbreviations: CUELA, computer-assisted, quantitative, recording and long-term analysis system; OCRA, occupational repetitive action.

Laboratory rodents generally are held in barrier facilities in plastic cages of various sizes on different types of bedding, and food and water typically are provided ad libitum. Soiled cages are exchanged for those with new bedding every 1 to 3 wk, depending on the number of animals per cage and on the management procedures of the animal facility. Routine tasks including emptying and washing cages, dispensing new bedding, washing and refilling water bottles, and transporting bedding and chow are either highly repetitive tasks or involve frequent moving of heavy loads.

In state-of-the-art facilities, routine tasks increasingly are carried out by robots, and automatically guided vehicles, as an upcoming technology, represent a new step toward automation in this work environment. However, in the majority of existing animal facilities, routine tasks, for the most part, are still performed manually. For this reason, personnel who work in the washrooms of large animal facilities execute great numbers of highly repetitive, actions each work day. Highly repetitive work can lead to monotony, stress, and psychologic saturation, and the static postures, frequent bending, and torsion of the trunk involved in doing these tasks place workers at considerable risk for musculoskeletal problems.[13,14,27] For quantitative analyses of body postures and repetitive movements during the different operations of the total workflow, close observation of the staff within fixed time intervals or video recordings with postwork analysis of the postures[28] have provided insight into the physical loads associated with various work environments.[12,19,23,37,38] However, highly detailed and continuous recording of postures requires the use of sophisticated sensors, either attached singly to the proband[22] or complex sensor systems worn during actual work.[30]

To quantify the workload generated by the regular workflow in an animal facility's washroom, we categorized regularly occurring washroom tasks into 8 characteristic operations and determined the musculoskeletal load of each operation by using a mechanical–electronic, computer-assisted recording and long-term analysis (CUELA) system.[5,7-9,11,15,18,20] The data indicated that different operations have various effects on distinct parts of the musculoskeletal system, depending on the type of movements within an individual operation, the weight of the materials, and the frequency of repetition.

Materials and Methods

Materials and workflow. The regular workflow in the washroom was divided into 8 operations, which are summarized in Table 1. Major tasks of the washroom staff include collection of materials from the animal holding rooms by using trolleys, emptying and washing of soiled caging material, and promptly supplying sterilized cages with approximately 65 g wood shavings (Lignocel S 3/4, Rettenmaier, Rosenberg, Germany) as bedding.

The term 'caging material' included polycarbonate type II (500 to 600 g each) and type III cages (1150 g each) with either wire grid, solid stainless, or plastic lids; chow hoppers; and water bottles. Chow and bedding bags weighing 10 to 15 kg each were delivered on pallets from the storage room to the washrooms

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Table 1. Categorization of operations in the washroom workflow in order of relative frequency

Operation	Description	Proportion of work flow (%)
Cages fill in bedding	Filling clean cages from the tunnel washer conveyor belt with an aliquot of wood shavings and stacking the filled cages on a trolley	46.3
Cages empty and wash	Emptying dirty cages from a trolley into a discharge funnel of a pneumatic bedding disposal station and placing the empty cages on the conveyor belt of the tunnel washer	42.5
Bottles transport	Collecting, stacking, and transporting clean water bottle racks from the rack washer and tunnel washer and to the autoclave	3.5
Bottles tunnel washer	Collecting and transporting trolleys with water bottle racks each containing 36 water bottles; loading the tunnel washer	3.5
Bedding bags handling	Lifting 12.5-kg bedding bags from pallets, carrying them to the dispensing station, and emptying the bedding into a container	3.1
Chow bags handling	Lifting 10- and 15-kg chow bags from pallets (delivered by fork lifts) and carrying them to a disinfection bath	0.9
Bottles rack washer	Collecting and transporting trolleys with water bottle racks each containing 18 water bottles; loading the rack washer	0.2
Trolley maneuvers	Pushing of trolleys loaded with water bottle racks or cages from the tunnel washers to the autoclaves or holding rooms or both	not determined

with a fork lift and lifted singly by hand to the site where the contents were dispensed into cages. Soiled bedding from cages was discarded into the funnel of a vacuum bedding disposal system (Dustcontrol, Norsborg, Sweden), and the cages were washed in tunnel washers with a belt speed of 720 to 1560 cages hourly. Clean cages were filled with bedding manually and transported by trolley back to the autoclaves and subsequently to animal holding rooms.

During the observation period, 24,000 mouse cages (type II: UNO, Zevenaar, Netherlands; type III: GM500, Techniplast, Buguggiate, Italy) of the total holding capacity of 35,000 were in regular use. The cage change interval was 7 d, implying that approximately 24,000 cages, lids, chow hoppers, and water bottles were processed each week.

Study group. The study group included employees of the central laboratory animal facility. Due to the division of labor in this facility, 8 employees with an average of 18.1 (2.5 to 33) y of service, including supervisor, deputy, and 6 staff members, worked exclusively in the 3 washrooms. Two healthy, 38- to 48-y-old, semiskilled, right-handed men, weighing 74 and 82 kg and measuring 168 and 170 cm in height without a previous history of workplace-related injury, volunteered to wear the CUELA system (Figure 1) while executing the various washroom operations. Ethical issues of this study were approved by the Department of Human Resources and by the Workers' Council of the institution. Each operation was recorded for at least 30 min, with 5 to 10 min breaks between recording sessions. Wearing the CUELA system did not impede the habitual activities of the test persons. Because the 2 participants were similar in body stature and the ways they executed the operations, resulting data were pooled.

Body posture and movements: measurements. The effects of the 8 routinely executed operations (Table 1) on musculoskeletal load in the washroom was determined by using the CUELA system,[5,7,8,15,18] which was developed by the Institute for Occupational Safety and Health of the German Social Accident Insurance Company (St Augustin, Germany). The CUELA system determined the range of movement in several dimensions for the head; cervical, thoracic, and lumbar spine; shoulder and elbow joints; and limbs during actual work (Table 2). Movements were measured by using inclinometers, gyroscopes, and potentiometers. The CUELA system weighed approximately 3 kg and was attached to the body and limbs of the participant (Figure 1). Data were recorded by using a 96-channel data logger (maximum, 22 MB per hour) on a 192-MB standard flash chip. Parallel videotaping of all movements facilitated kinematic reconstruction of the each volunteer's movements and their association with the CUELA-derived data. The measurement system and data evaluation have been described in detail elsewhere.[5,7,8,15,18]

Body postures and movements: evaluation. CUELA data provided detailed information on movements of the vertebral column, shoulder, and upper limbs for each operation. At the start of measurements, the CUELA system was calibrated to a neutral body posture (Figure 1), according to the neutral-zero method.[17] The ranges of angles of the movements of trunk and upper limbs were classified as 'acceptable' (or neutral), 'conditionally acceptable'(depending on frequency, holding time, and the actual weight handled at the respective body angles), and 'not acceptable' (Table 2) according to the subsequent musculoskeletal load and risk for development of musculoskeletal disorders.[4,6,21,29] Postures held for longer than 4 s at a constant or slightly changing force level were designated 'static.'[3] For each operation, movements are statistically described by the joint angle frequency distribution in the 5th, 25th, 50th, 75th, and 95th percentiles, where negative and positive values indicate the direction of movement (Table 2). Data were analyzed and evaluated with the CUELA software.[11] Postures and movements labeled as 'conditionally acceptable' and 'not acceptable' were considered to be strenuous.

Figure 1. The CUELA measurement system. Volunteer in the neutral–zero position ([A] front and [B] rear views), wearing the CUELA system which consists of sensors (at [C] shoulder and [D] elbow) and a miniature computer attached by a belt system. Postures for the operations (E) 'cages empty and wash' and (F) 'cages fill in bedding.'

Repetitiveness. Repetitive movements were defined as cycles of movements that were repeated in the same way for more than 30 min nonstop. We used the classifications of Silverstein[34] and Kilbom[26] to evaluate repetitiveness from CUELA data as number of movements per minute. Movement frequencies involving

Table 2. Assessment of movements and body angles

Movement	Direction of movement (+)	Direction of movement (–)	Body angles: acceptable	Body angles: conditionally acceptable[a]	Body angles: not acceptable[a]	Reference
Neck flexion right	to the right	to the left	–10° to 10°	not applicable	> 10° and < –10°	21
Neck flexion forward	flexion	extension	0° to 25°	not applicable	> 25° and < 0°	21
Trunk flexion	flexion	extension	0° to 20°	20° to 60°	> 60° and < 0°	21
Trunk lateral flexion	to the right	to the left	–10° to –10°	–10° to –20° and 10° to 20°	< –20° and >20°	21
Back flexion	flexion	extension	0° to 20°	20° to 40°	> 40° and < 0°	this study
Shoulder adduction	adduction	abduction	0° to –20°	–20° to –60°	< –60° and >0°	4
Shoulder flexion	flexion	extension	0° to 20°	20° to 60°	< –0° and >60°	4
Shoulder rotation	inward	outward	–15° to 30°	15° to –30° and 30° to 60°	< –30° and >60°	this study
Elbow flexion	flexion	extension	60° to 10°	not applicable	< 60° and >100°	29
Forearm pronation	pronation	supination	–30° to 20°	–30° to –55° and 20° to 40°	< –55° and >40°	6
Wrist flexion	flexion	extension	–25° to 20°	–25° to –50° and 20° to 45°	< –50° and >45°	6
Wrist radial duction	radial duction	ulnar duction	–10° to 10°	–10° to –25° and 10° to 15°	< –25° and >15°	6

The symbols (+) and (–) indicate opposite directions of movement.
[a]From references 4 and 21.

arms and hands that exceeded 10 per minute were defined as 'highly repetitive' tasks.

Risk index. For risk assessment, we applied the Occupational Repetitive Actions (OCRA) risk index, a method for calculating a concise index of exposure to repetitive movements of the upper limbs.[2,16,33] The risk factors and their corresponding multipliers, defined as 'posture' (CUELA), 'force,'[1] 'duration of the repetitive task,' and 'lack of recovery,' defined here as the absence of micropauses, and an additional work organization score were considered. The number of technical actions was counted from the CUELA data; means were multiplied by the number of cages handled per day. The Rating of Perceived Exertion was introduced by Borg[1] as a way of estimating the effort of a certain physical activity and was applied by using a linear 1 to 10 scale signifying 'no effort at all' (score, 0) to 'very very strong effort' (score, 10). OCRA indices less than 2.0 suggest no risk of injury due to repetitive movement; 2.1 to 3.9, low risk; 4.0 to 7.9, moderate risk; and 8.0 or greater, high risk of injury.

Handling loads. The Key Indicator Method represents , a means of assessing working conditions for lifting, holding, carrying, and pulling and pushing.[35,36] The equation for the total score for 'pull and push' was

$$(a + b + c + d) \times t,$$

where a is load score, b is accuracy of positioning and speed of motion, c is posture, d is the conditions and environment score, and t is time. The equation for calculating the total score for 'lift, hold, and carry' was

$$(a + c + d) \times t.$$

A rating score of less than 10 points corresponds to risk level 1, indicating low strain, with health risk due to physical overstraining unlikely. A score of 10 to 24 points corresponds to risk level 2, indicating increased strain. At this level, physical overstraining of persons with decreased ability to carry loads (that is, employees older than 40 y or younger than 21 y, newcomers to the job, and persons with impaired performance because of illness) is possible. A score of 25 to 49 points corresponds to risk level 3, indicating substantially increased strain, such that even persons fully able to carry loads might experience physical overstraining. Scores of 50 points or greater correspond to risk level 4, indicating high strain, likely physical overstraining, and the need for work organization measures.

Results

Individual operations as proportions of total washroom workflow. On the basis of calculations of the recorded frequencies of the individual operations and the average material throughput weekly, the 2 volunteers spent 42.5% and 46.3% of their daily shifts performing the operations 'cages empty and wash' and 'cages fill in bedding' (Table 1). The operations 'bottles rack washer,' 'bottles tunnel washer,' and 'bottles transport' represented 0.2%, 3.5%, and 3.5%, respectively, of the daily workflow. 'Chow bags handling' and 'bedding bags handling' represented 0.9% and 3.1%, respectively, of the total daily work. The operation 'trolley maneuvers' and the time required for daily cleaning of the washroom at the end of the shift, varied considerably and were not included in the evaluation.

Postures and movements of trunk and back. Except for the 2 operations 'cages empty and wash' and 'bedding bags handling,' the remaining 6 operations involved 'not acceptable' backward trunk extensions in the 5th percentile of the trunk angle frequency distribution; 'chow bag handling' involved 'not acceptable' backward trunk extensions in the 25th percentile (Table 3). The operations 'bottles rack washer,' 'bottles transport,' and 'bedding bags handling' involved 'not acceptable' back flexions in the 95th percentile. Of the 200 determinations, 37 were 'conditionally acceptable.' These results predominantly occurred in the 5th or 95th percentile (or both), except for the operations 'bottles rack washer' and 'bedding bags handling.' which were in the 75th and 25th to 75th percentiles, respectively. Of the 200 determinations, 153 were in the acceptable range. All sideward trunk flexions, forward back flexions, and back torsions to the right were either acceptable or conditionally acceptable.

Postures and movements of neck, shoulders, and arms. During all operations, 'not acceptable' neck flexions to the left occurred in the 5th percentile (Table 4). 'Not acceptable' forward neck flexions were detected during all operations in the 95th percentile, whereas 'not acceptable' backward neck flexions occurred in the 5th percentile. All other neck angles were in the acceptable range.

'Not acceptable' and 'conditionally acceptable' shoulder movements were detected in both dimensions (that is, adduction–abduction and flexion–extension) for a notable percentage of the measurement time. The proportion of 'not acceptable' movements was lowest for 'cages empty and wash'

Table 3. Angle distribution of trunk and back postures given in percentiles (P05–P95) during 8 representative operations of the washroom workflow

Operation	Percentile	Trunk flexion forward	Trunk flexion sideward	Back flexion to the right	Back flexion forward	Back torsion to the right
Cages empty and wash						
	P95	*20.3*	9.7	10	*31.6*	8.9
	P75	6.8	5.2	5.4	13.5	4.7
	P50	3.7	1.7	2.3	10.6	1.8
	P25	1.6	−1.3	−0.2	8.6	−1.7
	P05	−1.2	−6.0	−4.4	5.9	−8.5
Cages fill in bedding						
	P95	*22.9*	*10.3*	8.2	*35.0*	7.0
	P75	7.8	5.1	3.1	16.1	1.0
	P50	3.2	−0.1	−0.9	12.6	−3.0
	P25	0.6	−5.6	−4.7	9.8	−6.5
	P05	**−2.7**	−11.6	−9.4	6.8	*−10.4*
Bottles rack washer						
	P95	*47.7*	*11.7*	6.7	**50.8**	nd
	P75	*22.9*	5.3	2.1	*31.8*	nd
	P50	6.8	0.3	−1	19.2	nd
	P25	0.3	−3.5	−4.8	13.3	nd
	P05	**−5.4**	*−10.1*	*−12.3*	4.4	nd
Bottles tunnel washer						
	P95	*−32.3*	*11.6*	6.6	*38.2*	9.1
	P75	9.7	4.5	0.8	18.3	2.8
	P50	2.5	−0.3	−2	8.1	−1
	P25	−1.2	−5.1	−5.6	4.1	−5.4
	P05	**−6.8**	*−11.2*	*−11.9*	0.9	*−11.5*
Bottles transport						
	P95	*32.9*	*10.6*	8.7	**41.3**	9.3
	P75	10.1	3.4	3.3	19	1.8
	P50	4.2	−0.7	−0.1	13.9	−2.2
	P25	0.6	−4.5	−3.6	8.7	−5
	P05	**−4.8**	−9.8	−8.6	0.9	*−11.4*
Chow bag handling						
	P95	*25.3*	8.9	6.8	*24.4*	*10.9*
	P75	7.5	3.6	1.3	−10.5	4.6
	P50	1.9	−0.5	−1.6	7.1	−1.2
	P25	**−2.0**	−4.3	−4.6	4.1	−5.4
	P05	**−7.4**	*−10.1*	*−10.2*	0.1	*−12.3*
Bedding bags handling						
	P95	*30.8*	7.6	5.7	**44.2**	*13.0*
	P75	*24.6*	4.4	1.7	*34.1*	7.5
	P50	*20.3*	2.3	−0.3	*31.5*	2.2
	P25	9.4	−1.3	−2.3	*21.1*	−1.8
	P05	0.7	−7.1	−7.4	13.7	−5.9
Trolley maneuvers						
	P95	14.1	6.7	5.2	*20.1*	*13.6*
	P75	8.8	2.0	0.8	15.6	3.2
	P50	4.4	−1.0	−1.6	12.2	0.0
	P25	−0.2	−4.2	−4.2	9.1	−2.5
	P05	**−9.8**	−9.1	−8.7	2.7	−9.4

nd, not determined.
Plain, italic, and bold figures indicate body angles that were acceptable, conditionally acceptable, and not acceptable,[4,21] respectively.

Table 4. Angle distribution of neck,. shoulder, and upper limbs postures given in percentiles (P05–P95) during 8 representative operations of the washroom workflow

	Neck flexion to the right	Neck flexion forward	Shoulder adduction		Shoulder flexion		Elbow flexion		Forearm pronation		Wrist flexion		Wrist radial duction	
			left	right	left	right	left	right	left	right	left	right	left	right
Cages empty and wash														
P95	4.6	**27.3**	1.2	−6.5	**75.8**	*51.6*	95.7	95.4	*39.5*	*36.6*	17.9	10.0	1.4	5.1
P75	−0.6	17.4	−4.3	−12.0	*58.0*	*29.6*	93.2	81.5	*27.6*	9.7	6.9	−2.4	−2.9	0.0
P50	−4.1	9.8	−8.9	−16.5	*39.3*	17.1	69.1	72.1	12.2	−5.7	−1.6	−11.8	−5.3	−7.9
P25	−7.5	4.1	−15.6	*−22.7*	*25.4*	8.2	**53.0**	**57.9**	−0.2	−15.8	−8.5	−21.0	−7.8	*−10.3*
P05	**−13.8**	**−5.9**	*−32.6*	*−35.6*	11.3	0.9	**34.1**	**28.4**	−23.9	*−34.6*	−17.9	*−30.9*	*−14.5*	*−13.3*
Cages fill in bedding														
P95	5.4	**26.0**	0.8	**2.8**	**66.3**	**67.8**	**103.7**	93.2	*38.9*	**40.9**	*26.3*	*26.8*	5.2	5.7
P75	−0.1	15.6	−10.1	−14.7	*50.0*	47.6	89.6	70.5	*25.9*	*23.9*	10.0	13.2	2.2	0.5
P50	−4.1	8.8	−19.8	*−23.4*	*40.3*	*32.1*	73.8	**55.1**	14.3	7.8	2.2	2.7	−1.5	−4.0
P25	−7.8	2.9	*−28.7*	*−31.6*	*28.9*	13.7	**56.2**	**42.0**	−0.3	−7.5	−5.8	−8.0	−5.4	−8.0
P05	**−14.0**	**−6.2**	*−39.1*	*−47.7*	13.8	**−5.9**	**32.9**	**23.1**	−24.8	*−29.1*	−15.9	*−27.7*	*−11.1*	*−12.9*
Bottles rack washer														
P95	6.9	**35.1**	**12.3**	**23.8**	**88.1**	**97.2**	84.5	80.4	*38.4*	**47.9**	13.6	*31.5*	5.3	7.0
P75	0.0	21.6	−0.7	−5.3	*51.8*	**75.8**	65.2	60.5	*25.2*	*37.3*	6.3	16.5	1.9	3.6
P50	−0.4	8.5	−3.6	−18.9	*23.8*	**64.1**	**49.7**	**44.6**	*21.7*	*26.9*	2.2	9.1	0.5	1.5
P25	−6.1	0.2	−7.0	*−26.0*	5.9	*51.5*	**39.0**	**31.7**	16.3	11.0	−8.6	0.8	−1.3	−1.0
P05	**−14.8**	**−7.6**	−15.2	*−52.8*	0.7	*23.2*	**26.8**	**19.3**	−0.9	*−27.4*	−20.3	−16.8	−5.6	−5.3
Bottles tunnel washer														
P95	7.6	**30.4**	**9.5**	**6.2**	*55.2*	**73.5**	92.0	90.7	*23.4*	*36.1*	15.7	12.9	3.3	3.2
P75	0.4	20.1	−0.4	−3.4	*35.7*	*53.9*	74.7	63.2	7.7	14.4	5.3	−0.8	−0.4	−1.0
P50	−3.4	12.1	−5.6	−14.4	*20.1*	*39.1*	**59.8**	**45.1**	−5.2	−3.2	−0.8	−8.4	−3.0	−3.8
P25	−8.9	4.1	−11.7	*−27.8*	6.7	*23.9*	**42.5**	**28.7**	−16.0	−21.6	−8.4	−15.0	−5.5	−6.0
P05	**−17.6**	**−6.6**	*−25.9*	*−44.2*	**−5.6**	3.6	**23.2**	**12.7**	*−36.0*	*−41.9*	−22.3	*−28.7*	*−10.8*	*−10.7*
Bottles transport														
P95	8.3	**31.9**	**17.3**	**13.4**	**71.1**	**76.1**	94.7	88.7	*35.2*	**45.1**	*22.0*	17.8	2.6	3.9
P75	1.1	19.2	0.2	−3.4	*49.4*	53.2	78.3	69.0	19.3	*25.9*	10.2	6.8	−0.2	−0.4
P50	−2.2	11.2	−8.0	−16.3	*32.1*	*41.3*	**59.7**	**51.0**	6.7	5.2	1.7	−2.4	−2.9	−3.9
P25	−7.4	3.8	−19.8	*−31.4*	16.6	*26.6*	**41.2**	**32.6**	−7.1	−14.0	−9.0	−12.5	−6.2	−7.0
P05	**−15.0**	**−8.1**	*−40.9*	*−51.0*	2.5	10.9	**20.4**	**14.8**	*−25.8*	*−30.7*	−23.6	*−29.3*	*−11.2*	*−10.4*
Chow bag handling														
P95	8.8	**28.0**	**13.1**	**9.9**	*44.8*	*55.5*	96.4	94.2	*22.5*	*22.6*	*20.9*	8.1	1.3	2.7
P75	1.2	17.7	**4.3**	0.5	*22.7*	*34.7*	81.5	73.9	5.3	−0.9	9.1	−1.1	−1.3	−0.8
P50	−3.7	10.7	−1.2	−3.3	11.7	*20.4*	71.7	60.4	−7.7	−17.6	1.8	*−7.7*	−3.4	−3.3
P25	−8.8	3.0	−6.1	*−7.7*	2.6	9.3	**54.9**	**36.9**	−21.7	*−30.4*	−4.1	−15.1	−6.1	−5.3
P05	**−16.4**	**−11.8**	−13.2	*−22.6*	**−10.6**	**−6.7**	**23.9**	**11.3**	*34.4*	**−55.6**	−15.8	*−27.5*	*−11.3*	−9.5
Bedding bags handling														
P95	5.3	**41.3**	0.1	−2.5	*54.0*	**71.1**	78.1	80.6	*29.6*	*29.2*	*20.2*	**45.2**	3.3	6.4
P75	0.0	**36.1**	−4.2	−11.6	*40.7*	*48.8*	60.7	60.8	23.2	14.1	14.5	*33.2*	0.1	3.8
P50	0.0	23.7	−6.5	−16.6	*35.9*	*38.2*	**45.1**	**46.3**	11.7	−0.2	7.0	17.8	−1.6	2.2
P25	−4.5	5.5	−10.3	*−24.4*	*26.8*	*26.9*	**36.5**	**36.1**	−0.5	−12.9	1.4	5.9	−3.7	0.4
P05	**−15.4**	**−6.4**	−18.5	*−31.4*	11.5	9.8	**17.7**	**16.3**	−11.4	*−29.6*	−6.7	−14.7	−6.5	−2.9
Trolley maneuvers														
P95	**10.6**	**26.0**	**17.2**	**21.4**	**75.0**	**92.6**	90.5	95.3	**52.5**	**60.6**	8.5	10.0	*10.4*	9.3
P75	2.9	12.0	**2.4**	−1.2	*58.8*	**71.2**	68.8	64.5	*29.0*	**42.9**	−0.1	−0.7	3.9	5.5
P50	−1.5	4.2	**−3.5**	−11.1	*44.5*	*60.0*	**55.4**	**48.1**	19.6	*25.7*	−10.2	−9.6	1.4	2.2
P25	−6.1	**−2.8**	−9.6	*−21.3*	18.8	*38.3*	**38.1**	**33.5**	10.2	12.0	−18.9	−21.8	−0.2	−0.5
P05	**−12.8**	**−11.9**	*−27.5*	*−41.1*	4.3	8.9	**20.6**	**17.2**	−10.7	−10.7	**−51.7**	*40.9*	−3.8	−4.8

Plain, italic, and bold figures indicate body angles that were acceptable, conditionally acceptable, and not acceptable, respectively.[4,21]

and 'bedding bags handling'; the highest proportions occurred during 'trolley maneuvers,' followed by 'bottles rack washer' and 'chow bags handling,' both of which operations involved transporting heavy loads (Table 4).

Flexions of the right and left elbows reached the 50th percentile and therefore fell, for the most part, into the 'not acceptable' range during all operations, except for 'cages empty and wash' and 'chow bag handling.' All other angles of elbow flexion were in the acceptable range.

Forearm pronations in the 'not acceptable' range occurred in the 95th percentile during 4 of the 8 operations (Table 4) and in the 75th and 95th percentiles during 'trolley maneuvers.' Only 'chow bags handling' showed forearm supinations in the 'not acceptable' range. Conditionally acceptable angles occurred during all operations for supination in the 5th percentile and for pronation mostly in the 95th percentile. In addition, 7 of 8 operations had conditionally acceptable angles in the 75th percentile. In 3 measurements concerning the operations 'bottles rack washer' and 'trolley maneuvers,' awkward postures ('conditionally acceptable' and 'not acceptable') were found from the 50th percentile upward.

Most flexions of the wrist were within the acceptable range during all operations; conditionally acceptable angles were restricted to the 5th or 95th percentile (or both). 'Not acceptable' angles were recorded only during 'bedding bags handling' and 'trolley maneuvers' in the 95th and 5th percentiles, respectively (Table 4).

Wrist movements in the transverse plane (that is, radial and ulnar deviation) created the least strain. No 'not acceptable' angles during any of the 8 operations, and only scattered 'conditionally acceptable' angles were recorded. During 'bedding bags handling' and 'bottles rack washer' all angles were in the 'acceptable' range.

Repetitiveness. During the various operations, the joints of the shoulder, elbow, forearm, and wrist of the volunteers showed between 1 and 63 repetitions of a particular movement or contraction each minute (Table 5). The operations 'cages empty and wash' and 'cages fill in bedding', which accounted for the highest proportions of the workflow (42.5% and 46.3%, respectively; Table 1), were the most repetitive, at 23 and 55 repetitions per minute, respectively. Handling bottles, chow, and bedding were intermediate in repetitiveness, at 10 and 42 per minute, and 'trolley maneuvers' revealed the smallest values—between 9 and 30 per minute.

In the arms, the highest repetition was recorded for the elbows, with greater values for the right elbow in 6 of 8 operations, followed by forearm pronation or supination, wrist flexion or extension, and shoulder movements. For shoulder and elbow joints, movements were predominantly in the sagittal plane, with flexions in the shoulder and extensions in the elbow. The left and right wrists each showed 1 to 6 movements per minute on the transverse plane, signifying radial and ulnar deviation. According to benchmarks of 'high repetitiveness,'[26] all joints of shoulder and arms, except for radial duction of the wrist, revealed at least 10 movements or contractions per minute and therefore were determined to have experienced highly repetitive actions.

OCRA risk index: total load on upper limbs. The highly repetitive operations 'cages empty and wash' and 'cages fill in bedding' showed an average cycle time of 3.6 s. Individual employees performed these tasks for periods of 1 h per shift to a full work day. Therefore, we further evaluated these operations by using the OCRA index.[2,16,33] The number of actions performed was calculated from recorded CUELA data and the workflow in the washroom (Table 6). Force according to the Borg scale[1] was set to 1.0 for 'cages empty and wash,' given that cages were light in weight and because the employee's arms rested temporarily on the workbench. The force assigned for 'cages fill in bedding' was 1 because the employee's arms were continuously in motion. The additional influence factor was fixed at 0.95 for both operations, due to the negligible opportunity of the employee to make personal adjustments in how he performed these operations because the work pace was determined by the speed of the tunnel washer. Since lack of recovery time was not detected, the recovery factor was set at 1.0. Taken together, the OCRA risk indices for the operations 'cages empty and wash' and 'cages fill in bedding' both were between 0.8 and 0.9 and therefore suggested negligible risk for the development of upper limb musculoskeletal disorders (Table 6).

Static postures of upper limbs and cervical spine. Short intermittent static postures that lasted 4 to 10 s were identified for the shoulder, elbow, and cervical spine (data not shown). These postures occurred during all operations recorded. During 'cages empty and wash,' static postures lasting 10 to 30 s were identified and occurred mainly due to the faster work speed as compared with the actual speed of the tunnel washer. During both this operation and the static postures, the hands and arms of the volunteers rested repeatedly and for various durations on and were supported by the work surface. Additional static postures between 10 and 30 s occurred during 'bottles rack washer' operation and provided strain relief during those operations, which were associated with heavy loads.

Handling loads. Using the Key Indicator Method[35,36] to assess the load during 'pull and push' of fully loaded trolleys resulted in a score of 15 points, which represents risk level 2. Calculating the load during 'lift, hold, and carry' of different loads resulted in values between 12 and 32 points, representing risk levels 2 and 3. For example, on the basis of 4000 cages processed daily, the task 'bottles tunnel washer' had a score of 20 points (risk level 2), and the shifting of 400 piles of cages or bottle racks resulted in a score of 36 points (risk level 3). Taken together, handling of all loads in the washroom workflow achieved a risk level of 2 or 3, on a scale of increasing risk of 1 to 4.

Discussion

Quantitative analyses of the musculoskeletal loads of washroom employees during their daily routine revealed an increased load on the upper limbs, which was greatest on the shoulders and elbows, during all operations. This increased load mainly was due to the range of movements and their repetitiveness. The risk of developing musculoskeletal disorders from handling loads that involved 'pull and push' and 'lift, hold, and carry' movements was calculated as 2 to 3, on a 1 to 4 scale of increasing risk. In contrast, the load resulting from adverse trunk postures was negligible, because they occurred only briefly.

The current study was done in a centralized laboratory animal facility, which is organized by division of labor and divided into different holding areas and 3 central washrooms. At the time of the investigation, 52,000 small rodents, 90 dogs, and 90,000 zebrafish were bred and held at the facility. The rationale for the study was the observation that the annual sick leave rates among washroom staff over a 10-y period were 4 times higher than those of staff in the dog or zebrafish areas and 4 times higher than national averages. Whereas the overall workflow and individual operations in the washrooms are considered to be repetitive and predominately monotonous and stationary, those in the dog and fish areas are diversified, more sophisticated, and less dependent on fixed workplace positions. Staff members in

Table 5. Shoulder, elbow, forearm, and wrist movements (no. per min) during the execution of 8 representative operations of the washroom workflow

	Shoulder adduction or abduction		Shoulder flexion or extension		Elbow flexion or extension		Forearm pronation or supination		Wrist flexion or extension		Wrist radial or ulnar deviation	
	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
Cages empty and wash	*19*	*16*	25	25	**55**	**48**	**34**	**46**	**36**	*26*	4	1
Cages fill in bedding	23	**37**	**40**	**34**	**44**	**63**	**34**	**48**	**49**	**37**	5	6
Bottles rack washer	*13*	*18*	*14*	*23*	25	**35**	*11*	*14*	*19*	*21*	2	0
Bottles tunnel washer	*14*	*20*	*20*	*25*	*28*	**35**	*11*	*17*	*21*	*28*	4	2
Bottles transport	*20*	*24*	*17*	*20*	**33**	**39**	*19*	*20*	*27*	*28*	4	3
Chow bags handling	*17*	*20*	*23*	*28*	**37**	**42**	*19*	*24*	*28*	**34**	4	3
Bedding bags handling	*10*	*21*	*17*	*25*	*27*	**36**	*12*	*18*	*24*	*12*	0	0
Trolley maneuvers	*16*	*22*	*13*	*16*	*26*	**30**	9	*11*	*13*	*16*	2	1

Operations with between 10 and 29 (italics) and 30 or more (bold) movements per minute are defined as highly repetitive.

Table 6. OCRA scores[a] of the upper limbs ($n = 2613$ actual technical actions for each arm) for the 2 most time-consuming tasks

	Cages fill in bedding		Cages empty and wash	
	Right arm	Left arm	Right arm	Left arm
Factors				
Force (Borg scale)	1	1	0.85	0.85
Posture (CUELA)	0.7	0.7	0.7	0.7
Additional factors[b]	0.95	0.95	0.95	0.95
Net duration of repetitive task (min)[c]	160	160	175	175
Lack of recovery	1	1	1	1
No. of actions recommended[d]	3192	3192	2968	2968
OCRA index	0.8	0.8	0.9	0.9

[a]A higher score indicates an increased risk of injury
[b]Lack of influence on work flow and design (range, 0 to 1)
[c]Waiting periods and additional work were excluded
[d]Calculated on the basis of a frequency constant of 30 actions per minute

the washroom frequently reported chronic pain in spine, shoulder, upper limbs, elbow, and wrist, and 7 of 8 washroom staff required medical care including orthopedic surgeries in 5 of the 8 employees within the past 10 y. To quantitatively analyze all regular washroom tasks and extrapolate their influence on the musculoskeletal load of the staff members in these areas, we divided the regular workflow comprising processing of cages and associated materials, as well as transport and allocation of water, chow, and bedding, into 8 characteristic operations and analyzed each operation with respect to body posture and movements by using the CUELA system.

The 2 operations 'cages empty and wash' and 'cages fill in bedding' encompassed nearly 90% of the daily working flow. Contributions from the 6 remaining operations ranged from 0.2% to 3.5% per operation. However, 'trolley maneuvers,', which comprised movements with the heaviest weights, were not assessed quantitatively. These actions were completed alternately and for brief times by staff executing the more monotonous work, which was associated with lightweight loads (for example, filling the tunnel washer), with the intention of counteracting imminent monotony.

The risk resulting from adverse trunk and back postures appeared to be negligible. When these postures were associated with high weights, they were adopted only for short periods of time (as in the cases of 'chow bags handling' or 'bottles rack washer'), or they resulted from unfavorable work heights during the handling of racks with bottles or stacking of cages. For postures associated with lightweight objects, the work height of 96 cm at the tunnel washer seems appropriate for employees who are about 170 cm tall. Bringing this work height in line with the variable heights of different employees would reduce the proportion of 'not acceptable' postures further.

In contrast to the findings for trunk and back, the results for postures and movements of neck, shoulder, and arms revealed increased musculoskeletal loads during all operations. These loads resulted both from the range of motions of both limbs, irrespective of preference for left or right, as well as from the high fraction of 'conditionally acceptable' and 'not acceptable' angles engaged during these operations.

Of the movements and body parts investigated in the current study, adduction and flexion of the shoulders and flexion of the elbows, together with right and forward flexions of the neck, showed the highest proportions of angles in the 'not acceptable' range. This observation is in good agreement with the notion that the 5 orthopedic surgeries reported by staff members during the past 10 y, involved shoulders, elbow, and wrists.

Associations between occupational factors and the occurrence of specific disorders of the upper extremity have been studied widely, and detailed data have been summarized, although different workplaces were described and different methods were applied.[32,37,38] Two comprehensive literature reviews[37,38] concluded that highly repetitive work, together with awkward postures, are risk factors for specific shoulder disorders. Further, a number of physical work factors may increase specific disorders of the elbow. This risk has been shown to be associated with an increase in the number of years of exposure to repetition.[37,38]

The OCRA index determined for the 2 most time-consuming operations 'cages empty and wash' and 'cages fill in bedding' did not indicate that employees had an increased risk of developing musculoskeletal disorders of the upper limbs. However, repeated physical exertion that does not immediately cause damage can, over time, induce injuries.[25] Typically, the main cause of musculoskeletal disorders is the combination of various risk factors. Moreover, adverse effects from repetitive work increase when awkward postures and forceful exertions are present.[24] In addition, such disorders may come about after a critical number of years of service at a particular workplace or due to continuous execution of the same operation.[37,38] The current investigation is not a longitudinal study, and we did not include the factor of number of service years and therefore could not evaluate this factor's influence on development of musculoskeletal disorders.

During all operations, shoulders and arms experienced more than 10 movements per minute; therefore all movements (except for radial deviation of the wrists) were defined as highly repetitive.[26] Repetition frequencies of flexion and extension of shoulder, elbow, forearm, and wrist were highest during cage processing, with a maximum of 63 movements per minute for the right elbow. Although the same number of cages was processed on either side of the tunnel washers, these frequencies typically were higher for 'cages fill in bedding' than for 'cages empty and wash', due to the fact that on the clean side, 2 products had to be brought together (that is, clean cages and a defined amount of clean bedding), thereby requiring more movements. It seems obvious that introduction of robotics and automation would greatly alleviate the downside of cage processing, which is still performed by hand in most facilities.

Assessment of the loads encompassing 'lift, hold, and carry' and 'push and pull' treatment of bottles, bags, and trolleys revealed values between 2 and 3 on a 1-to-4 scale of increasing load. This load, however, occurs only in rare cases, when the same person performs either one or both of these operations during an entire shift. For example, 'trolley maneuvers' is in risk area 2. In such cases, appropriate measures (such as reduction of bag weights and alternate assignment to different operations) should be considered.

In the present study, all operations that were either associated with heavy loads or highly repetitive usually were alternately assigned to the staff during the daily shifts. Therefore, with respect to the material flow and the total number of staff working in the washrooms, the workload was considered acceptable. However, this consideration did not take into account the high number of years of service of most of the employees.

The present study provides quantitative data on the musculoskeletal load and repetitiveness of actions in animal facility washrooms. The CUELA data together with the ensuing OCRA index indicate no increased risk for musculoskeletal disorders on the basis of the material flow and number of staff assigned to washrooms. However, the various disorders among staff during the past 10 y imply an increased risk for musculoskeletal disorders of the upper limbs, indicating the factor of the service time as a critical determinant. Consequently, once critical workplace factors have been identified, specific measures should be considered to alleviate musculoskeletal loads on staff and improve ergonomics over the long term and on a managerial basis.[24,31,32]

Managerial intervention, including alternation and rotation of workplace assignment and extension of cage change intervals, as well as technical interventions, such as adjustment of work heights and reduction of overall weights of bags and materials, may improve the quality of the workplace. Sustainable, conceptual changes, particularly in cage processing, including implementation of robots and vacuum technologies for 'cages empty and wash' and 'cages fill in bedding' operations as well as the handling of loads by using automatically guided vehicles, forklifts, and cranes, require substantial investments and, in most facilities, redesign of workflow and infrastructure. However, such technical advancements likely improve workplace quality, washroom efficiency, and productivity and subsequently may change the staff's job satisfaction, performance, and health for the better. These facility changes should be considered in view of return on investment and improving the work environments of washrooms in animal facilities.

The current ergonomic study describes a specific workplace that is common among large animal facilities. We focused on the staff in the washrooms and their most prevalent, routinely occurring work tasks, by using the highly sophisticated CUELA system. The methods we used allowed us to assess the risks of developing musculoskeletal disorders when staff performed such work tasks. Although high numbers of sick days and chronic musculoskeletal disorders among the washroom staff were part of our motivation for performing the study, the study design was not suited to unequivocally explain existing injuries. Therefore, a limitation of this study is that the present data can neither prove nor rule out a cause-and-effect chain. The design of a study that would highlight such issues would have to be either retrospective or prospective, including a larger sample group and the use of additional methods. For statistical reasons, the future investigation would have to be a multicenter study, because the number of washroom staff at a single animal facility is not sufficiently large to generate significant findings. Our study aimed at stimulating discussions regarding possible cause-and-effect chains, especially for staff who have worked in washrooms for many years. Further, the data obtained in the current study can be used as a basis for in-depth follow-up investigations.

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