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Posture and lifting exposures for daycare workers

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ABSTRACT

Daycare employees, specifically caregivers, are a distinct population that may experience increased risk of injury due to the high exposure to bent postures, lifting conditions and high stress associated with their work. The objectives of the study were to collect up to date data on daycare workers and to compare the data between groups working with children of different ages (Infant, Toddler and Preschool). The study consisted of two distinct phases: Phase 1 – Questionnaire distribution, Phase 2 – Observation and analysis involving three dimensional postural monitoring and video recording as well as an analysis of the low back forces and moments in lifting. Phase 1: Consisted of the distribution of questionnaires to all employees in each of the participating daycares ($n = 73$). Of the 73 questionnaires distributed 32 responses were obtained (44%). Of the 32 employees who completed the questionnaires, 19 caregivers volunteered to participate in Phase 2 of the study. An additional 5 caregivers participated in phase 2 of the study, but did not complete any questionnaires. The questionnaires indicated 81% of the workers have experienced low back pain. Phase 2: Observational data were collected on site in five local daycares, throughout the first half of each subject's shift (~3.5 h). Caregivers from each of the three classroom age groups were recruited for participation in the direct observation (Infant: $n = 7$, Toddler: $n = 7$, Preschool: $n = 8$). Posture analysis revealed that on average, workers adopted trunk flexion angles greater than 55°, for 10% of the collection time, and greater than 70°, for 5% of the collection time. These postures correspond to both moderate and severe flexed postures respectively. The lifting analysis (completed using the data recorded in phase 2) revealed that workers lifted with frequencies of 0.25 lifts/minute, lifted a total weight of 501 kg (over 3.3 h) and experienced average compression and shear forces of 3323 N and 371 N, respectively. A between-group comparison showed that when compared to the Preschool group, the Infant ($p = 0.008$) and Toddler ($p = 0.001$) groups demonstrated higher relative flexed postures and lifting frequencies, and the Toddler group ($p = 0.023$) demonstrated higher total weight lifted. Results suggested that these employees experience an elevated risk of low back injury caused by their occupational tasks and thus, further research is required to determine appropriate worker accommodations and safe work practices to help mediate these risks for all daycare caregivers.
Relevance to industry: It is thought that the results from this study could lead to the development of safe working and job sharing guidelines for daycare workers.

1. Introduction and background

Daycare workers are a specific population that has had little attention in the research community in recent years, with most of the research taking place in the 1990's and early 2000's. In a 2012 statistical supplement published by the Workplace Safety and Insurance Board (WSIB) of Ontario, workers in the daycare/homecare field contributed to 7% of all reported workplace injuries (WSIB, 2012). With this incidence of work-related injury, it is imperative

Abbreviations: PS, Pain Survey; DJS, Demographics and Job Survey; EVA, Exposure Variation Analysis; APDF, Amplitude-Probability Distribution Function; 3D-SSPP, University of Michigan's Three Dimensional Static Strength Prediction Program; EMG, Electromyography.

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that interventions are researched to help mitigate this injury risk.

Brown and Gerberich (1993) used statistical information to examine the rate, type and mechanisms of injury experienced by daycare caregivers. The results found the back and upper/lower extremities to be the most common areas of injury; while the most common mechanisms of injury were worker overexertion and falls (Brown and Gerberich, 1993). In another study, some of the ergonomic factors that could cause increased worker injury were identified (Swanson et al., 1994). Some of the factors identified were: lifting, bending, stooping, squatting and carrying loads. Additionally, high-risk tasks including lifting children to change tables, bending to use equipment and carrying children were identified (Swanson et al., 1994). Working posture has also been associated with self-report discomfort in the neck/shoulder, back, and lower limbs. This is dependent both on time spent working, and on sitting versus standing work. On average, discomfort increased over the course of the shift; but self-reported discomfort decreased when the subject was able to sit while working. Surprisingly, this was not the case in the back, as seated work increase back discomfort when compared to standing (Antle et al., 2015).

In the same period, a study was performed in Quebec daycare centres including a full ergonomic assessment and physical demands analysis of the conditions of workers and facilities. The results suggested that injuries were primarily caused by falls and tasks involving excessive effort and movement (Markon and Le Beau, 1993). Owen (1994) performed a 4-hour workplace observation of worker-identified “difficult tasks”, and recorded information involving worker performance. Workers were observed based on: lift duration, bending, twisting, and foot position. The employees reported lifting, specifically children, to be the most physically demanding tasks. Recommendations for improvement included: implementing assisted lifting, the use of chairs with increased back support, and improvement of toilets, cribs, and sinks (Owen, 1994). In 1996, King and colleagues observed workers on the job and noted the differences between the child age groups. Results suggested that there are different physical demands placed on the caregivers depending on the child group (King et al., 1996).

In terms of measurement, other studies have instrumented the worker to record quantifiable injury risk data and have related this data to self-report postural data obtained from questionnaires. Self-report data from questionnaires targeting worker mobility and control over posture were found to be useful additions to studies with observational components, particularly when relating working conditions to musculoskeletal outcomes (Laperrière et al., 2005). Inclinometers, capable of recording forward trunk inclination posture, showed a forward flexed posture of 20°, on average, and substantial percentage of worker time spent in postures in higher flexed postures (Kumagai et al., 1995). In addition to measuring trunk inclination, Shimaoka et al. (1998) also measured worker heart rate, step count, sit/stand time and lifting parameters. These researchers also examined caregivers with different child age groups and found workers in the younger groups experienced higher musculoskeletal and lifting/carrying demands (Shimaoka et al., 1998).

The previous research has led to the development of safe-lifting guidelines and ergonomic recommendations to help limit the exposure to these injury risks among this working population. This information has been presented in the form of brochures (OHCOW, 2012; Everest Re Group Ltd., 2010; UTexas.edu, (n.d.)), training programs (UTexas.edu, 2013), and information booklets (California Childcare Health Program, 2006). Despite this, it is unclear whether these resources are being used in employee training programs, and if the recommendations have been implemented in the workplace.

Based on the review of literature presented, there has been little quantitative field research conducted in the past decade. With advances in technology and more knowledge on worker injury exposure and safety, daycare data were collected to determine if any changes had been implemented since the early observations and to see if workers in this field are still exposed to these work risk factors. Therefore, the objectives of the current study were to evaluate postural and lifting demands in a sample of daycare workers, and compare these demands between the caregivers in three child age groups.

2. Methods

The protocols employed in the current study, as well as all recruitment and dissemination strategies have been approved by Queen's University's General Research Ethics Board.

2.1. Phase 1 – questionnaires

2.1.1. Subjects

Caregivers were recruited from five daycares in the Kingston, Ontario area. Within each of the daycares a set of questionnaires, one dealing with history of worker injury and the other with demographics and work, were distributed for all workers to complete (73 sets of questionnaires total).

2.1.2. Data collection

Two questionnaires were distributed to all employees. The first served to determine worker demographics and work experience (called the Demographics & Job Survey (DJS)). This survey included questions related to experience working in a daycare, educational background, health and safety training, and history of occupational injury. Finally, the questionnaire ended with a brief survey aimed to examine the employee's knowledge of safe lifting practices and determine whether they had ever received lifting training on the job. The second questionnaire (Pain Survey (PS)) identified areas of pain using an Extended Nordic Questionnaire (Dawson et al., 2009) and a modified Borg Scale (Borg, 1990) with a pain map. Additionally, the Oswestry Disability Index examined the effects of back pain on worker function (Fairbank and Pynsent, 2000).

2.1.3. Data processing

Questionnaire responses were summarized and general trends were recorded. Of particular interest were the areas of pain or discomfort, outlined in the Extended Nordic Questionnaire as well the areas and pain scores identified by the Borg Scale.

2.2. Phase 2 – field data collection

2.2.1. Subjects

Of those caregivers who completed and returned the questionnaires from Phase 1, 19 volunteered to continue on with the study. These 19 individuals, as well as an additional 5 caregivers (who did not complete any questionnaires) participated in phase 2 of the study ($N = 24$ volunteers: $n = 23$ females, 1 male; height $= 163.9 \pm 7.9$ cm, weight $= 72.0 \pm 15.7$ kg). Phase 2 involved an observation and measurement component, lasting approximately four hours. The daycares divide the children in three age groups: Infant (0–1.5 years), Toddler (1.5–~2.5 years) and Preschool (~2.5–~4 years). Preference was given to individuals with a minimum of 1 year experience working in a daycare, however provided the participants had completed the required education program for an Early Childhood Educator diploma, complete with mandatory placements, this experience threshold was not enforced. The average years of experience for all workers were 8.11 ± 9.6 years.

2.2.2. Data collection

The field collection involved instrumentation of the caregiver using a three-dimensional postural dosimeter, developed by Plamondon et al. (2007). The dosimeter contained two inertial measurement units (IMUs) representing the orientation of the upper trunk and the pelvis. They were positioned at the T1 and S1 spinal levels, respectively (Fig. 1). Each IMU contained a set of three sensors including: a gyroscope, accelerometer and magnetometer capable of determining the sensor orientation at both spinal levels. An additional rod system, connected at one end to a rotating potentiometer, served as another method used to measure trunk axial twist. The change in sensor orientation was transmitted, via Bluetooth, to a handheld computer (iPAQ: Hewlett Packard, CA, USA), where it was stored on an 8 GB SD card. The screen on the iPAQ allowed the researcher to ensure that the data storage was proceeding continuously (i.e. the computer did not freeze, storage did not stop for any reason), however it did not allow for a real-time display of angle data. Subject posture was collected continuously, in three directions: flexion/extension, lateral bending and twist, over the entire duration of the collection at a sampling frequency of 120 Hz. Postural data was represented with two reference systems. The first, absolute posture, was the orientation of the trunk with respect to the vertical estimated with the sensor at T1; and was collected in real-time in the field. The second, relative posture, was the orientation of the T1 sensor with respect to the S1 sensor; and was computed following the collection.

The instrumented workers were filmed throughout the collection with a capture rate of 30 frames/second. In order to synchronize the video data with the angle data, a signal was inserted into the angle trace and coincided with the onset of a light, which was recorded in the video. The frame containing the signal was then subsequently matched with the video frame containing the light (Fig. 2). Additionally, frames of video while lifting were used in a lifting analysis to determine spinal loads and moments. In order to complete the lifting analysis, loads at the hands were needed. Throughout the observation, the time of the lifts and magnitudes of all weights (>1 kg) lifted were recorded by a second researcher. Small hand loads (toys, storage containers) were weighed using a luggage scale (XScale: Heys International Ltd, ON, CAN). Larger loads (large toys, bins of toys) and children were weighed using a standard analog bathroom scale.

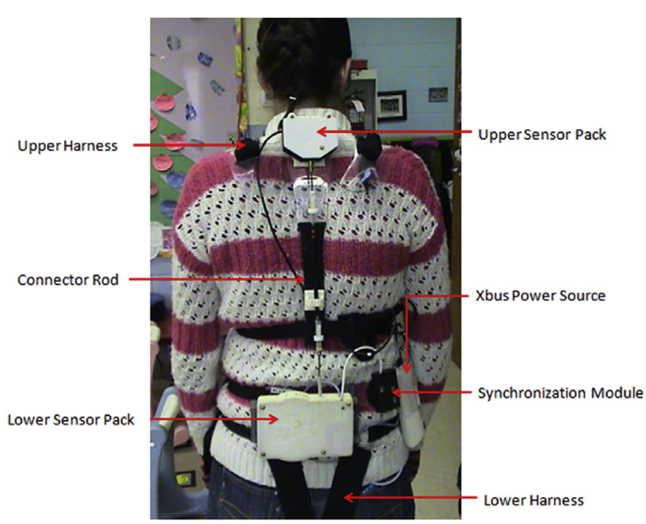

Fig. 1. Instrumentation of the dosimeter on a subject. Care was taken to place the upper and lower sensors at the T1 and S1 levels, respectively, as level as possible. Calibration of the unit accounted for any off-axis or off-level placement of the device on the subject's back.

Data collections for each instrumented worker took place in the mornings, and lasted approximately 3.5 h (195 ± 25.0 min). This period was selected as it allowed the caregivers to complete all of their tasks with the children including outdoor play, meal time, toileting, and naptime. Data were not collected in the afternoon, as the children were generally asleep for ~2 h (depending on age group), after which time the morning tasks were usually repeated.

2.2.3. Data processing

Using Kinovea Motion Analysis Software (Version 0.8.15), researchers examined each video recording and determined the lifting frequency, type of lift (stand, seated or kneeling), the percentage of lifts involving children and the total weight lifted.

The postural data were processed using a custom MATLAB (Version 2012b: MathWorks, MA, USA) script which integrated the angle data collected by the dosimeter with the video and the event timings defined by Kinovea. When run, the script is able to create Amplitude Probability Distribution Function (APDF: Jonsson, 1978) and Exposure Variation Analysis (EVA: Mathiassen and Winkel, 1991) plots that can be used to determine the range of postures to which workers are exposed and to identify the difficulty of individual tasks. APDF plots display the posture adopted by the individual with respect to the amount of time spent in that posture (probability of the worker adopting that posture). APDFs were created for: flexion/extension angle (trunk, pelvis and relative), lateral bending angle (trunk, pelvis and relative) and twist angle (relative).

EVA plots display the same information as an APDF, with an added dimension: the duration that a given posture was maintained. The 3D plots represent the percentage of total collection time spent within a certain range of angle and a certain range of duration. Therefore posture range (x axis) and duration range (y axis) are divided to create 2D bins. The percentage of total collection time spent in each bin is represented by a bar on the z axis (see Fig. 7). EVAs were created for: relative flexion/extension, lateral bending and twist angles as well as global flexion/extension and lateral bending angles.

The axes of the plots were made according to user-defined limits for posture and duration, and further subdivided this range into "bins" of smaller increments. The current study used angle bins in 10° increments for the entire range of angles, in all three directions. Flexion/Extension exhibited angles from $-30°$ to $+120°$, whereas lateral bending and twist angles ranged from $-60°$ to $+60°$; where negative values indicate rotation/bend to the left, or extension of the trunk. A logarithmic scale was used to define the duration bins with times that ranged from 0 to 64 s (i.e. 0–1, 1–2, 2–4, 4–8…). In addition to EVA plots, six summary scores were generated: three centered scores (Posture, Duration, and Exposure) which denote where the data was centered within the limits, and three distribution scores ($Posture_{SD}$, $Duration_{SD}$ and $Exposure_{SD}$) which describe the spread of the data (Delisle et al., 2006). Scores were compared between age groups.

The lifting analysis was conducted using still frames from the video for each lift in the 3-Dimensional Static Strength Prediction Program (3D-SSPP) from the University of Michigan. The frames of video were captured at the instant where the load became fully supported by the worker. In order to be counted the load lifted must exceed 1 kg and must leave the ground or have weight fully supported by subject. Additionally, there were several criteria for the use of images for the analysis. For example the employee must not have used any external support (i.e. leaning against a countertop, one hand on a table…), minimal blocking of the subjects posture (by furniture, etc) and the load needed to be fully visible. Images not meeting these criteria were omitted from the analysis.

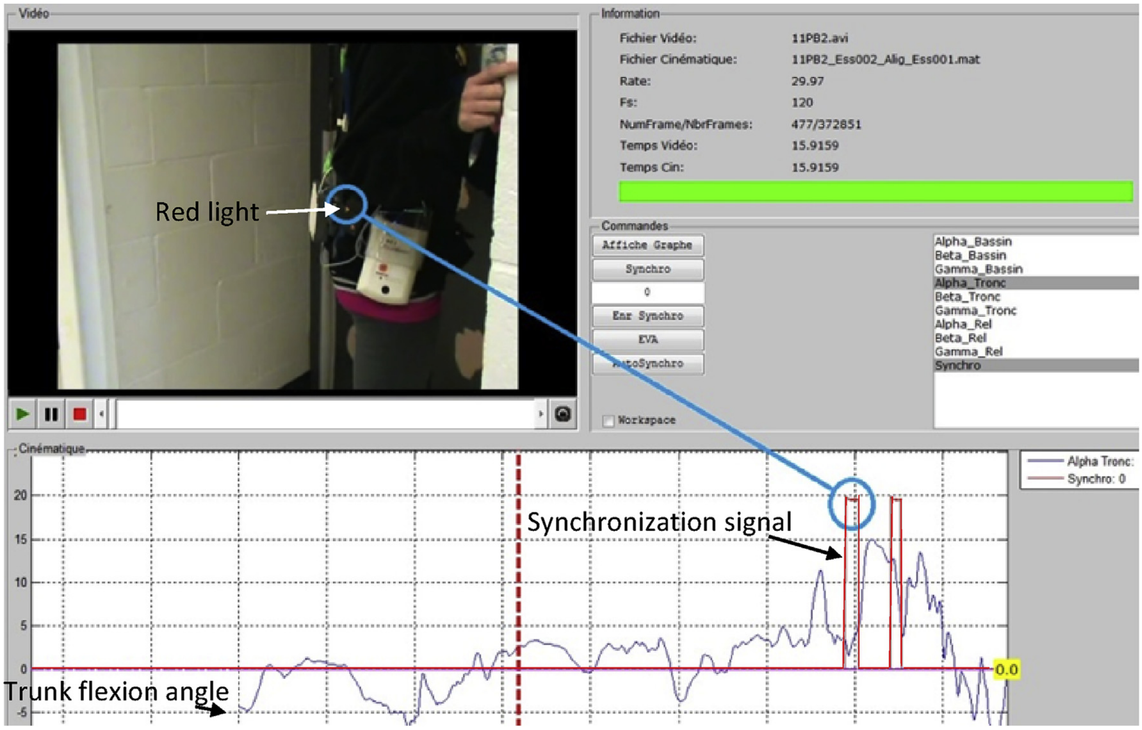

Fig. 2. The custom MATLAB software allowed the researchers to synchronize the flashing red light in the video with the spike in the synchronization signal in the raw posture data. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

3D-SSPP allows the user to position an avatar such that it matches the conditions experienced during the lift. External hand loads are applied, and using standard segment anthropometric estimations based on subject weight and height, the program is able to estimate lumbar compression (forces along the longitudinal axis of the spine) and shear forces (forces that run perpendicular to the longitudinal axis of the spine), as well as lumbar moments (Chaffin, 2007). The researchers attempted to orient the camera perpendicular to all lifts, however as the caregivers would often move or turn while lifting, this was not always possible. Fortunately, 3D-SSPP allows the avatar to be positioned in 3D space and therefore, with additional manipulation of the avatar, it could be rotated to match that seen in the video frame (Fig. 3).

Fig. 3. 3D-SSPP avatar overlayed on a frame of video data for one child lift.

2.2.4. Statistical analysis

One-way ANOVAs (alpha = 0.05) were used to identify any main effect of age group (Infant, Toddler and Pre School) on all variables of interest. In cases where a main effect was detected, Tukey post-hoc tests with Bonferroni adjustments were used to isolate the effect of the specific groups. Levene's Test of Homogeneity of variance was used to determine whether the data was normally distributed. If homogeneity of variance was not present ($n = 6$ cases: absolute and relative lateral bend APDF scores, forces and moments at L4/L5, and EVA scores (centre and distribution) for the total shift), Welch ANOVA with Games-Howell posh hoc was used in place of a standard One-way ANOVA with Tukey post hoc.

3. Results

3.1. Phase 1 – questionnaires

Within the five daycares sampled, there were 57 full time employees and 16 part-time/casual employees. Of the 73 questionnaire sets distributed, 32 were returned (30 full time, 1 part-time, 1 unknown), giving a return rate of 44%. Workers who returned the questionnaires had an average age of 34.8 ± 11.0 years and an average height and weight of 163 ± 10 cm and 71 ± 15 kg, respectively.

The results of the questionnaire showed that the majority of workers (81%) reported having experienced aches, pain, or discomfort in the low back followed by the neck and shoulders (59% each) (Fig. 4).

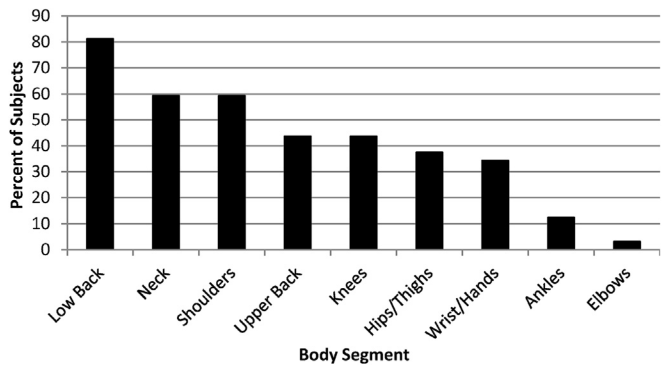

Fig. 4. Results of the Nordic Questionnaire, outlining specific regions of pain and injury among daycare caregivers.

3.2. Phase 2 – field data collection

3.2.1. Posture analyses

The results of the posture analyses are based on data from 22 of the 24 participants instrumented. Two subjects (I female, 1 male) were omitted due to equipment malfunction.

3.2.1.1. APDF – flexion/extension. On average, workers spent 50 percent of their time in a flexed posture of 17° and 23° and above for absolute and relative angles, respectively (Fig. 5A and B). Additionally, workers adopted absolute flexed postures of greater than 55° for 10% of the collection (~20 min) and flexed postures of greater than 70° for 5% of the collection (~10 min).

The ADPF for absolute angles (Fig. 5A) shows uniformity among the age groups, with very little differences seen in flexion angle for any group (Table 1). A small difference in extension angle was seen for the Toddler group when compared to Infant and Preschool groups, however this difference was not significant.

Contrarily, a main effect of age group on relative trunk flexion was seen at the 50th, 90th and 95th percentiles (Table 2). Post-hoc analyses revealed differences between the Infant and Preschool groups at the 50th percentile ($p = 0.033$); between the Infant and Preschool groups ($p = 0.048$) and Toddler and Preschool groups ($p = 0.039$) at the 90th percentile; and between the Toddler and Preschool groups ($p = 0.044$) and Infant and Preschool groups ($p = 0.05$) at the 95th percentile. This suggests that the younger age groups (Infant and Toddler) demand a greater degree of trunk flexion than the Preschool group.

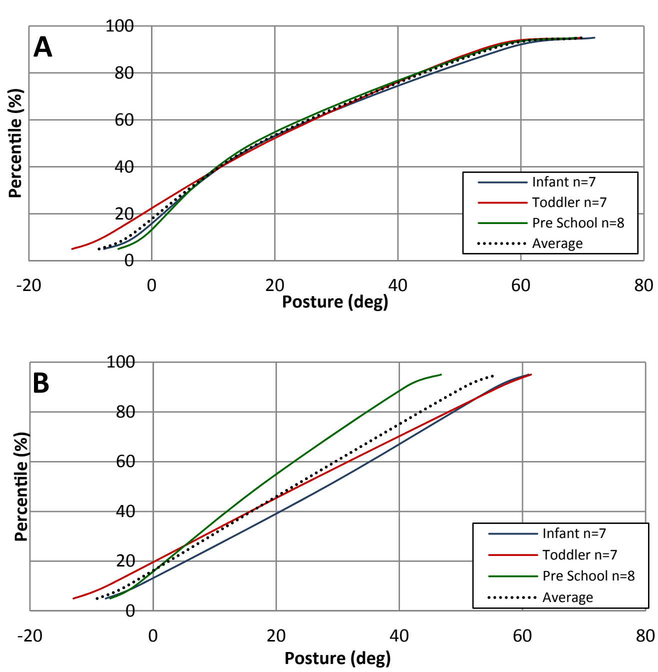

Fig. 5. A. Absolute flexion/extension angle for all age groups with the mean of all groups shown with the black dotted line where flexion is positive, and extension is negative. B. Relative flexion/extension angle for all age groups with the mean of all age groups shown with the black dotted line. Systematic differences between the two angle measurement methods are evident. Absolute angles are consistently higher in magnitude than relative angles, however show very little disparity between groups. Relative angles, while lower in magnitude show larger differences between age groups.

3.2.1.2. APDF – lateral bending. In lateral bending, where right is positive and left is negative, workers spent an even amount of time bent in either direction (Fig. 6), with no differences found between groups (Tables 3 and 4). Comparing the values at the extreme percentiles showed that, on average, workers spent approximately 10% of the shift laterally bent (to the right and left) in postures outside the −19° to +19° range.

3.2.1.3. APDF – axial twist. In axial twist, where negative is twisted to the left, and positive is twisted to the right, workers spent almost even time twisted in either direction, however slightly more time was spent twisted to the left (Fig. 7). No difference was found between groups (Table 5).

3.2.1.4. Exposure Variation Analysis – EVA. For the sake of brevity, only the three centered scores (Posture, Duration, Exposure) and the three distribution scores ($Posture_{SD}$, $Duration_{SD}$, $Exposure_{SD}$) for the EVAs were analysed. An example of an EVA plot is provided in Fig. 8.

There was no main effect of age group on centered scores (Table 6).

A significant main effect was found of age group on $Posture_{SD}$ in the relative flexion/extension. Post hoc analyses revealed a significantly larger distribution of data in the Preschool group than in the Infant group and in the Toddler group (Table 7). This indicates that the Toddler and Infant groups exhibited a significantly smaller range of postures than the Preschool group. No differences were found for the other distribution scores ($Duration_{SD}$ and $Exposure_{SD}$).

3.2.2. Lifting analysis

Several factors were examined in terms of the external effects on worker lifting including: maximum weight lifted, total weight lifted, and lift frequency. Internal physical demands, including compressive and shear forces were also analysed.

3.2.2.1. Weights and frequencies. Caregivers lifted a range of weights from 1 to 19 kg, with an average maximum weight of 14.3 kg. Additionally, workers lifted an average total (cumulative) weight of 501 kg during the data collection, ranging from 240 kg (SD = 225 kg) (for Preschool group) to 679 kg (SD = 319 kg) (for Toddler group). A main effect of age group on total weight lifted was found, and post hoc analysis revealed significantly higher weight lifted for the Toddler compared to the Preschool group (Table 8).

On average, workers lifted with a frequency of 0.25 lifts/minute, ranging from 0.15 lift/min (Preschool) to 0.33 lifts/min (Toddler). A main effect of age group on lifting frequency was found, and post-hoc analyses showed significantly higher lifting frequencies in the Infant and Toddler (Table 8) groups compared to the Preschool group. Of more concern however, based upon observations

Table 1
Results from ANOVA analysis for the APDF 5th, 10th, 50th, 90th, and 95th percentiles for Absolute trunk flexion angles.

Direction	Percentile	Means (standard deviations)			Between-group ANOVA results			Post-Hoc	
		Infant	Toddler	Preschool	Mean square	F	Sig	Sig	Meaning
Absolute Flexion	5	−8 (6)	−13 (6)	−5 (6)	108.79	2.86	0.08		
	10	−3 (6)	−8 (6)	−1 (6)	82.63	2.30	0.13		
	50	18 (5)	18 (5)	16 (6)	6.91	0.26	0.77		
	90	57 (11)	53 (15)	54 (8)	26.26	0.19	0.83		
	95	72 (10)	70 (15)	69 (10)	16.58	0.12	0.89		

Table 2
Results from ANOVA analysis for the APDF 5th, 10th, 50th, 90th, and 95th percentiles for Relative trunk flexion angles.

Direction	Percentile	Means (standard deviations)			Between-group ANOVA results			Post-Hoc	
		Infant	Toddler	Preschool	Mean square	F	Sig	Sig	Meaning*
Relative Flexion	5	−8 (10)	−13 (7)	−7 (8)	76.99	1.07	0.36		
	10	−3 (9)	−8 (7)	−3 (7)	54.80	0.90	0.42		
	50	28 (10)	24 (4)	17 (8)	224.66	3.82	0.04	0.033	I > P
	90	56 (6)	56 (14)	41 (11)	571.99	4.65	0.02	0.048	I > P
	95	61 (6)	61 (14)	47 (11)	530.10	4.51	0.03	p< 0.05	I/T > P

*I = Infant, T = Toddler, P = Preschool, I/T = Infant & Toddler.

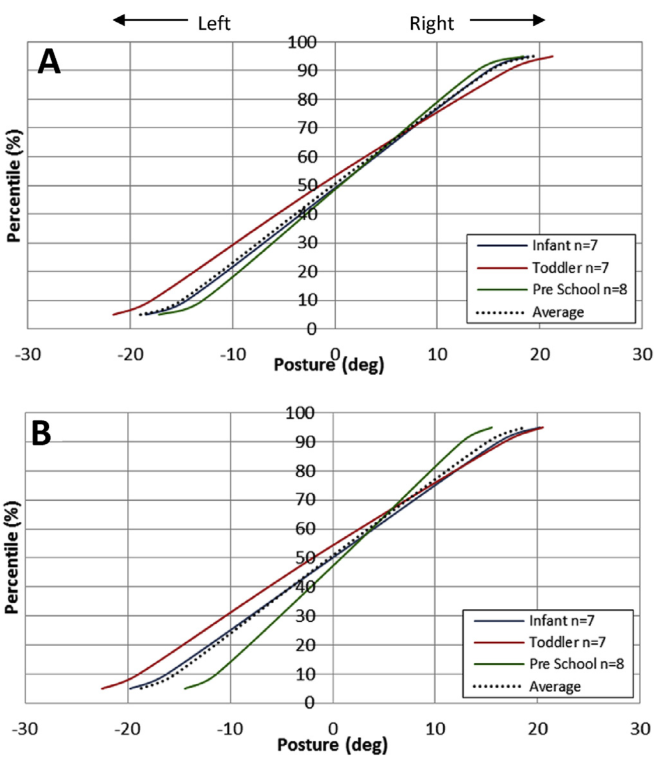

Fig. 6. A. Absolute lateral bend angle for all age groups with the mean of all groups shown with the black dotted line. B. Relative lateral bend angle for all age groups with the mean of all age groups shown with the black dotted line. While the relative angles again show a larger disparity than the absolute angles, the range of angles is within a healthy posture.

recorded during the data collection, is the timing of these lifts. At times (such as before naptime, or while preparing for outdoor play), all children would be treated for the same issue (diaper changes, dressing in snow clothes) at the same time, often by one employee, while the other employees are playing with the remaining children. This results in the lifting of up to 15 children in 30–45 min thereby greatly increasing the frequency of lifts (>30 lifts/hour or 0.5 lifts/minute). This occurred 2–3 times during the collection (5–6 times) per day.

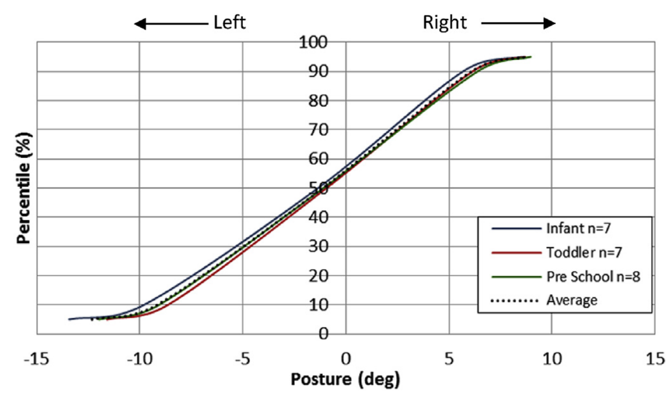

Fig. 7. Axial twist angle for all age groups with the mean of all groups shown with the black dotted line. With a 50th percentile at ~2°, the APDF suggests that the workers spent slightly more time twisted to the left.

3.2.2.2. Compression and shear. Average peak L4/L5 compressive forces for child lifts across all workers for Infant, Toddler, and Preschool age groups were 3392 (SD = 600) N, 3612 (SD = 688) N, and 2965 (SD = 814) N, respectively. There was no significant main effect of age group on compressive force (Table 9).

Average peak L4/L5 shear forces for child lifts across all workers for Infant, Toddler, and Preschool age groups were 373 (SD = 57) N, 406 (SD = 117) N, and 335 (SD = 94) N, respectively. There was no significant main effect of age group on shear force (Table 9).

Average peak L4/L5 moments for child lifts across all workers for Infant, Toddler, and Preschool age groups were 156 (SD = 26) N, 176 (SD = 41) N, and 151 (SD = 50) N, respectively. There was no significant main effect of age group on lumbar moment (Table 9).

4. Discussion

4.1. Postural exposure

Flexed postures have been classified as mild (<20°), moderate (20° to 60°), and severe (>60°) in terms of their associated risk for the development of low back disorders (Takala et al., 2010). The results from the current study revealed approximately 45% of the time in a moderate injury exposure range, and approximately 5%

Table 3
Results from ANOVA analysis for the APDF 5th, 10th, 50th, 90th, and 95th percentiles for Absolute lateral bend angles for the trunk.

Direction	Percentile	Means (standard deviations)			Between-group ANOVA results			Post-Hoc	
		Infant	Toddler	Preschool	Mean square	F	Sig	Sig	Meaning
Absolute Lateral Bend	5	−18 (5)	−22 (4)	−17 (4)	38.51	1.88	0.18		
	10	−14 (5)	−18 (4)	−13 (4)	48.16	2.62	0.10		
	50	0 (3)	−1 (6)	0 (2)	8.23	0.52	0.60		
	90	15 (2)	17 (4)	14 (4)	16.83	1.54	0.24		
	95	19 (2)	21 (3)	18 (5)	16.88	1.31	0.29		

Note: Levene's Test of Homogeneity of variance was used to determine whether the data was normally distributed. As homogeneity of variance was not present, Welch ANOVA with Games-Howell post hoc was used in place of a standard One-Way ANOVA with Tukey post hoc for this analysis.

Table 4
Results from ANOVA analysis for the APDF 5th, 10th, 50th, 90th, and 95th percentiles for Relative lateral bend angles for the trunk.

Direction	Percentile	Means (standard deviations)			Between-group ANOVA results			Post-Hoc	
		Infant	Toddler	Preschool	Mean square	F	Sig	Sig	Meaning
Relative Lateral Bend	5	−20 (8)	−23 (6)	−14 (5)	127.72	3.21	0.06		
	10	−16 (7)	−19 (6)	−11 (4)	111.44	3.19	0.06		
	50	−0.1 (2)	−2 (6)	1 (2)	14.90	1.06	0.37		
	90	16 (6)	17 (5)	13 (5)	38.74	1.45	0.26		
	95	20 (7)	20 (5)	16 (5)	59.38	1.88	0.18		

Note: Levene's Test of Homogeneity of variance was used to determine whether the data was normally distributed. As homogeneity of variance was not present, Welch ANOVA with Games-Howell post hoc was used in place of a standard One-Way ANOVA with Tukey post hoc for this analysis.

Table 5
Results from ANOVA analysis for the APDF 5th, 10th, 50th, 90th, and 95th percentiles for Relative axial twist for the trunk.

Direction	Percentile	Means (standard deviations)			Between-group ANOVA results			Post-Hoc	
		Infant	Toddler	Preschool	Mean square	F	Sig	Sig	Meaning
Relative Axial Twist	5	−13 (3)	−12 (4)	−12 (2)	6.54	0.64	0.54		
	10	−10 (3)	−9 (4)	−9 (2)	2.42	0.27	0.77		
	50	−1 (2)	−1 (3)	−1 (2)	0.30	0.05	0.96		
	90	6 (3)	6 (3)	6 (3)	0.96	0.11	0.89		
	95	9 (3)	9 (4)	9 (3)	0.34	0.03	0.97		

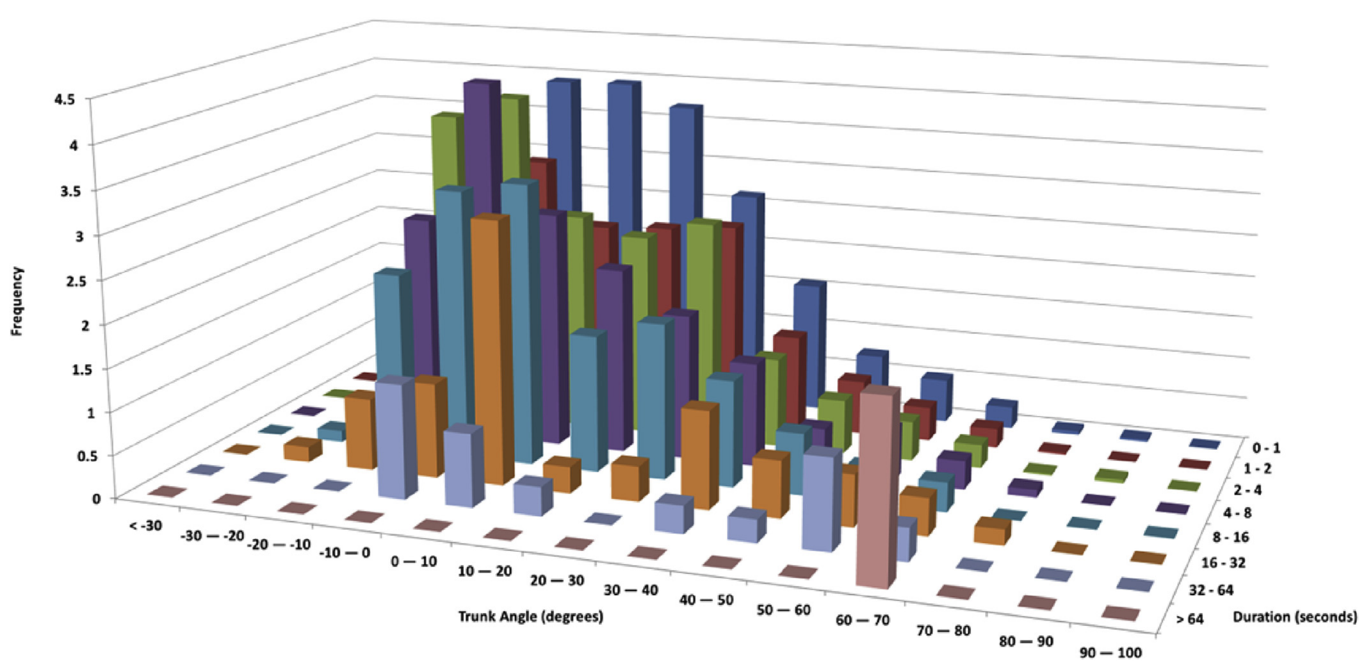

Fig. 8. EVA illustrating total time spent in flexion-extension in each of nine angle categories and eight duration categories (bins) for the entire observation period for a representative subject. Note, the Posture and Duration scores denote the value across which the data is centered on the x, and y, axes respectively. Exposure is a combination of these two scores. The Posture$_{SD}$ and Duration$_{SD}$ variables denote the spread (standard deviation) of these variables across each of their respective axes. Exposure$_{SD}$ is a combination of these two scores.

Table 6
Results from ANOVA analysis for the centered scores obtained for the total EVA for all subjects.

Direction	Score Category	Between-group ANOVA results			Post-Hoc	
		Mean square	F	Sig	Sig	Meaning
Absolute Flexion	Posture	0.04	0.14	0.87		
	Duration	0.04	0.28	0.76		
	Exposure	0.07	0.39	0.68		
Relative Flexion	Posture	1.54	3.09	0.07		
	Duration	0.09	0.41	0.67		
	Exposure	0.18	0.49	0.62		
Absolute Lateral Bend	Posture	0.03	0.51	0.61		
	Duration	0.07	0.52	0.60		
	Exposure	0.07	0.53	0.59		
Relative Lateral Bend	Posture	0.09	1.58	0.23		
	Duration	0.04	0.21	0.82		
	Exposure	0.03	0.16	0.85		
Relative Axial Twist	Posture	0.00	0.06	0.94		
	Duration	0.00	0.01	0.99		
	Exposure	0.00	0.01	0.99		

Note: Levene's Test of Homogeneity of variance was used to determine whether the data was normally distributed. As homogeneity of variance was not present, Welch ANOVA with Games-Howell post hoc was used in place of a standard One-Way ANOVA with Tukey post hoc for this analysis.

Table 7
Results from ANOVA analysis for the distribution (SD) scores obtained for the total EVA for all subjects.

Direction	Score Category	Between-group ANOVA results			Post-Hoc	
		Mean square	F	Sig	Sig	Meaning*
Absolute Flexion	$Posture_{SD}$	2.26	1.15	0.34		
	$Duration_{SD}$	1.33	0.27	0.76		
	$Exposure_{SD}$	0.05	2.19	0.14		
Relative Flexion	$Posture_{SD}$	10.16	6.38	0.01	$p < 0.05$	P > I/T
	$Duration_{SD}$	1.49	0.41	0.67		
	$Exposure_{SD}$	0.13	5.26	0.02	$p = 0.015$	P > I
Absolute Lateral Bend	$Posture_{SD}$	6.13	2.32	0.13		
	$Duration_{SD}$	1.65	0.41	0.67		
	$Exposure_{SD}$	0.09	2.09	0.15		
Relative Lateral Bend	$Posture_{SD}$	17.62	3.00	0.07		
	$Duration_{SD}$	1.12	0.25	0.78		
	$Exposure_{SD}$	0.20	2.42	0.12		
Relative Axial Twist	$Posture_{SD}$	1.04	0.56	0.58		
	$Duration_{SD}$	4.83	2.48	0.11		
	$Exposure_{SD}$	0.11	1.21	0.32		

Note: Levene's Test of Homogeneity of variance was used to determine whether the data was normally distributed. As homogeneity of variance was not present, Welch ANOVA with Games-Howell post hoc was used in place of a standard One-Way ANOVA with Tukey post hoc for this analysis.
*I = Infant, T = Toddler, P = Preschool, I/T = Infant & Toddler.

Table 8
Results from ANOVA analysis of lifting variables (weights and frequencies).

Variable	Means (standard deviations)			Between-group ANOVA results			Post-Hoc	
	Infant	Toddler	Preschool	Mean square	F	Sig	Sig	Meaning*
Frequency (lifts/min)	0.3 (0.1)	0.3 (0.1)	0.2 (0.1)	0.08	10.09	0.001	$p < 0.05$	I/T > P
Total Weight (kg)	584 (202)	679 (319)	240 (225)	319078.04	4.96	0.02	$p < 0.05$	I/T > P
Number of Lifts (lifts/collection)	56.1 (16.8)	67.9 (17.6)	29.7 (18.3)	3283.07	10.53	0.001	$p < 0.05$	I/T > P

*I = Infant, T = Toddler, P = Preschool, I/T = Infant & Toddler.

Table 9
Results of ANOVA analysis for low back forces (compression and shear) and moments at the L4/L5 level.

Spine level	Force direction	Means (standard deviations)			Between-group ANOVA results			Post-Hoc	
		Infant	Toddler	Preschool	Mean square	F	Sig	Sig	Meaning
L4/L5	Compression (N)	3392 (600)	3612 (688)	2965 (814)	6489690.06	1.30	0.30		
	Shear (N)	373 (57)	406 (117)	335 (94)	14937.44	0.87	0.44		
	Moment (Nm)	156 (26)	176 (41)	151 (50)	2020.78	0.62	0.55		

spent in the severe range. These results are similar to those found in previous studies which used <20°, 20°–45° and >45° as their posture exposure limits (Kumagai et al., 1995). These researchers found an average worker posture of 20.3° of flexion. The current study showed similar results, with a 50th percentile value of 17.4° absolute flexion, on average. Furthermore, Kumagai et al. found that workers spent 57.7% of time in a mild exposure range, 32.2% of time in a moderate range, and 10.6% of time in a severe range. Similarly, the current study found ~54% of time in a mild exposure range, ~28% of time in a moderate exposure range, and ~18% of time in a severe exposure range.

For lateral bending, 20° is said to increase risk for injury (David et al., 2008). In terms of lateral bending, workers spent approximately 10% of their time in laterally bent postures of ±19° approaching the suggested lateral bending limit.

In terms of the relative angles, no suggested exposure limits exist. Unlike the absolute angles, the relative angles indicate a more accurate depiction of worker posture and are more indicative of the physiological strain associated with large flexions.

When comparing across age groups, there were significant differences in relative flexion angles, demonstrating a tendency for the caregivers working with younger children to adopt greater flexed postures compared to the older group. Based on observations from the data collections, this difference could be attributed to differences in job demands related to the independence of the children. In the younger groups, many of the activities depend on worker-child interactions. In the older groups, workers play more of a supervisory role requiring less bending. Although these differences exist it is important that workers in all groups be observed in order to improve or limit their exposure to injury.

4.2. Lifting exposure

Lifting frequency was an important variable to consider, as repetitive loading can increase fatigue and risk of injury among workers (Craig et al., 2003). When examining the occurrence of daycare caregivers lifting children, Kumagai et al. (1995) reported lifting frequencies of 6.1 lifts/hour and Shimaoka et al. (1998), reported lifting frequencies of 23.5 lifts/hour in a Japanese daycare and 8.9 lifts/hour in a Swedish daycare. The current study found lifting frequencies of 17.9 lifts/hour, 19.8 lifts/hour and 9.12 lifts/hour in the Infant, Toddler and Preschool groups, respectively; which are in the range of values reported previously (Commissaris and Toussaint, 1997). While these values may not be excessive when compared to other manual materials handling jobs, it is expected that the risk for injury increases when a dynamic load of unknown mass is introduced.

NIOSH suggests a spinal compressive force limit of 3400 N as the acceptable limit and 6400 N as the maximum permissible limit. The current study revealed that, on average, workers experienced peak compressive forces of 3479 N at the L4/L5. Although average worker spinal compression forces did not exceed the suggested limit, this limit was exceeded in 7% of the lifts analysed. Additionally, Gallagher and Marras (2012) have recommended shear limits of 700 N for repetitive lifting and 1000 N for occasional lifting. In the current study, workers experienced shear forces of 395 N at the L4/L5 spinal level. Although, on average, the peak compressive and peak shear forces did not exceed the recommended limits, factors including repetition, fatigue and cumulative effects were not considered throughout the analysis and could affect the magnitudes of compression experienced. Furthermore, workers exposed to substantial lifting frequencies and moderate spinal loading (as in those seen in the current study) over long durations have an increased risk of developing MSDs.

NIOSH has suggested a recommended weight of 15.9 kg (35 lbs) for workers in the healthcare industry (Waters et al., 2006). This limit is suggested when moving patients, which unlike inanimate loads are not rigid, move, and do not always cooperate. In the current study, the average maximum weight was 14.3 kg and 22% of the workers lifted weights greater than 15.9 kg. Similarly, the Ohio lifting guidelines, created by Ohio State University and the Ohio Bureau of worker compensation (OBWC), suggest a limit of 9.1 kg. This limit was exceeded in 70% of the lifts recorded in the current study (Bureau of Workers' Compensation, 2012). While daycare caregivers are often lumped in the same category as healthcare workers at conferences and professional development seminars, there have been no specific lifting recommendations for these workers.

5. Conclusion and future work

The results from the current study suggest that several factors leave workers in the daycare field susceptible to injury. Responses from the questionnaires show that 81% of workers reported pain in the low back and 59% of respondents reported pain in the neck and shoulders.

This elevated prevalence of pain among this population could be a result of posture adopted in the workplace. The absolute flexion magnitudes suggest moderate to severe exposure, thereby increasing their risk for injury. Additionally, caregivers were found to have lifted 501 kg on average, over a typical half-shift (~3.3 h) with a frequency of 0.25 lifts/minute with moving children. While average peak compressive and shear forces were lower than the suggested limits from NIOSH and Gallagher & Marras at the L4/L5 and L5/S1 levels, occasionally these loads exceeded the recommended limits and are therefore a cause for concern.

Group comparison showed that caregivers working with Infant and Toddler groups adopted significantly higher relative flexed postures and lifted with a higher frequency compared to the Preschool group. Additionally, it was noted that the younger groups required the caregivers to adopt more awkward postures while lifting (often lifting from a seated or kneeling position). These awkward postures could increase the likelihood of a single-incident tissue strain, thereby increasing the injury risk among these caregivers.

Future work includes more research specific to daycare workers, collected through both observational and quantitative studies. Further observation could lead to the implementation of safety standards or guidelines for this population. A task-specific analysis would also allow researchers to locate the most dangerous tasks and suggest modifications that would help mitigate the risk for injury associated with these tasks.

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References

Antle, D., Vézina, N., Côté, J., 2015, February. Comparing standing posture and use of a sit-stand stool: analysis of vascular, muscular and discomfort outcomes during simulated industrial work. Int. J. Ind. Ergon. 45, 98–106.
Borg, G., 1990. Psychophysical scaling with applications in physical work and the perception of exertion. Scand. J. Work Environ. Health 16, 55–58.

Brown, M., Gerberich, S., 1993. Disabling injuries to childcare workers in Minnesota, 1985-1990: an analysis of potential risk factors. J. Occup. Med. 35 (12), 1236–1243.

Bureau of Workers' Compensation O, 2012, March 12, Division of safety & hygiene – lifting guidelines. Retrieved July 2014, from Ohio Bureau of Workers' Compensation: https://www.bwc.ohio.gov/employer/programs/safety/liftguide/liftguide.asp.

California Childcare Health Program, 2006. Staff Health in Early Childhood Education Programs. www.ucsfchildcarehealth.org. Training Booklet. (accessed 12.02.15.). http://www.ucsfchildcarehealth.org/pdfs/Curricula/CCHC/9_CCHC_Staff_Health_0606.pdf.

Chaffin, D., 2007. Human motion simulation for vehicle and workplace design. Hum. Factors Ergon. Manuf. 17 (5), 475–484.

Commissaris, D.A.C.M., Toussaint, H.M., 1997. Load knowledge affects low-back loading and control of balance in lifting tasks. Ergonomics 40 (5), 559–575.

Craig, B., Congleton, J., Kerk, C., Amendola, A., Gaines, W., Jenkins, O., 2003, May/June. A prospective field study of the relationship of potential occupational risk factors with occupational injury/illness. Am. Ind. Hyg. Assoc. 64 (3), 376–387.

David, G., Woods, V., Li, G., Buckle, P., 2008. The development of the quick exposure checklist (QEC) for assessing exposure to risk factors for work-related musculoskeletal disorders. Appl. Ergon. 39, 57–69.

Dawson, A., Steele, E., Hodges, P., Stewart, S., 2009. Development and test–retest reliability of an extended version of the nordic musculoskeletal questionnaire (NMQ-E): a screening instrument for musculoskeletal pain. J. Pain 10 (5), 517–526.

Delisle, A., Larivière, C., Plamondon, A., Imbeau, D., 2006. Comparison of three computer office workstations offering forearm support: impact on upper limb posture and muscle activation. Ergonomics 49 (2), 139–160.

Everest Re Group, 2010. Loss Control Alert: Child Care Back Injury Program. www.everestre.com. Brochure. (accessed 12.02.15.). http://www.everestre.com/Portals/0/Documents/Alerts/Child%20Care%20Back%20Injury%20Prevention%2011-10.pdf.

Fairbank, J., Pynsent, P., 2000. The oswestry disability index. Spine 25 (22), 2940–2953.

Gallagher, S., Marras, W., 2012. Tolerance of the lumbar spine to shear: a review and recommended exposure limits. Clin. Biomech. 27, 405–410.

Jonsson, B., 1978. Quantitative electromyographic evaluation of muscular load during work. Scand. J. Rehab. Med. Suppl. 6, 67–74.

King, P., Gratz, R., Scheuer, G., Claffey, A., 1996. The ergonomics of child care: conducting worksite analyses. Work 6 (1), 25–32.

Kumagai, S., Tabuchi, T., Tainaka, H., Miyajima, K., Matsunaga, I., Kosaka, H., Seo, A., 1995. Load on the low back of teachers in nursery schools. Int. Arch. Occup. Environ. Health 68 (1), 52–57.

Laperrière, E., Messing, K., Couture, V., Stock, S., 2005, April. Validation of questions on working posture among those who stand during most of the work day. Int. J. Ind. Ergon. 35 (4), 371–378.

Markon, P., Le Beau, D., 1993. La santé et la sécurité au travail pour les éducatrices en garderie. Université du Québec à Chicoutimi. QC : Commission de la Santé et de la Sécurité du Travail (C.S.S.T.), Chicoutimi.

Mathiassen, S., Winkel, J., 1991. Quantifying variation in physical load using exposure-vs-time data. Natl. Inst. Occup. Health Div. Appl. Work Phys. 34 (12), 1455–1468.

Occupational Health Clinics for Ontario Workers (OHCOW), 2012. Safe Lifting Techniques of Children. www.ohcow.on.ca. Brochure. (accessed 12.02.15.). http://www.ohcow.on.ca/uploads/Resource/General%20Handouts/Lifting%20Children%20Safely.pdf.

Owen, B., 1994. Intervention for musculoskeletal disorders among child-care workers. Pediatrics 94 (6 pt.2).

Plamondon, A., Deslisle, A., Larue, C., Brouilette, D., McFadden, D., Desjardins, P., Larivière, C., 2007. Evaluation of a hybrid system for three-dimensional measurement of trunk posture in motion. Appl. Ergon. 38 (6), 697–712.

Shimaoka, M., Hiruta, S., Ono, Y., Nonaka, H., Hjelm, E., Hagberg, M., 1998. A comparative study of physical work load in Japanese and Swedish nursery school teachers. Eur. J. Appl. Phys. 77 (1), 10–18.

Swanson, N., Piotrkowski, C., Curbow, B., Graville, S., Kushnir, T., Owen, B., 1994. Occupational health and safety issues in child-care work. Pediatrics 94 (6 pt.2), 1079–1080.

Takala, E., Pehkonen, I., Forsman, M., Hansson, G., Mathiassen, S., Neumann, W., Winkel, J., 2010. Systematic evaluation of observational methods assessing biomechanical exposures at work. Scand. J. Work Environ. Health 36 (1), 3–24.

University of Texas at Austin (UTexas), 2013. Ergonomics for Childcare Workers (OH 502). University of Texas at Austin. https://utexas.edu. Online Training Module. (accessed 12.02.15.). https://www.utexas.edu/safety/ehs/training/oh502/.

UTexas (n.d.) Safe Lifting for Child Care Workers. https://www.utexas.edu. Brochure. (accessed 12.02.15.). https://www.utexas.edu/safety/ehs/occupational/safe_lifting_for_childcare.pdf.

W.S.I.B, 2012, June Toronto. By the Numbers: 2012 WSIB Statistical Report. WSIB, Ontario, Canada, p. 76.

Waters, T., Collins, J., Galinsky, T., Caruso, C., 2006. NIOSH research to prevent musculoskeletal disorders in the healthcare industry. Orthop. Nurs. 25 (6), 380–389.