Survey of One-handed Lifting in Manufacturing Industry: A Cross-sectional Study of the BackWorks Study Cohort

Ruoliang Tang[1,2], Jay M. Kapellusch[1], Andrew S. Merryweather[3], Matthew S. Thiese[4], Kurt T. Hegmann[4], Sue A. Ferguson[5], William S. Marras[5], Ming-Lun Lu[6]

[1]Occupational Science and Technology, University of Wisconsin-Milwaukee
[2]Sichuan University-Pittsburgh Institute
[3]Mechanical Engineering, University of Utah
[4]Family and Preventive Medicine, University of Utah
[5]Spine Research Institute, The Ohio State University
[6]Division of Applied Research and Technology, National Institute for Occupational Safety and Health (NIOSH)

Low back pain (LBP) is a common health problem and a major cause of lost productivity in workplaces. Manual materials handling (MMH) jobs have traditionally been regarded as risk factor for LBP. Compared to two-handed lifting, one-handed lifting has received little attention in both epidemiological and biomechanical research. In addition, one frequent complaint of the revised NIOSH lifting equation (RNLE) has been the lack of capability to directly evaluate one-handed lifting. Modifications have been proposed by the European Union, however their efficacy and influence have not yet been evaluated. This cross-sectional study provided objective survey of the MMH jobs, especially the one-handed lifting performed in manufacturing industry and investigated the outcomes of three proposed methods to address one-handed lifting using RNLE approach. Preliminary results suggest that workers with some one-handed lifting are associated with higher physical exposure. However, the increase was more significant among those who perform primarily one-handed lifting.

BACKGROUND

In the United States (US), industrial workers continue to experience a high incidence rate of low back pain (LBP) (Bureau of Labor Statistics, 2015). Work-related LBP (WLBP) is one of the most frequent and disabling conditions affecting workers in their productive year (NIOSH, 1997), and is a major reason for early retirement and disability pensions (Andersson, 1981; Kim, Choi, Chang, Lee, & Oh, 2005). According to the Workers' Compensation Insurance Rating Bureau (WCIRB), the average cost per claim for back injuries increased from 2000 to 2010, averaging over $50,000 per case (CHSWC, 2011). WLBP claims represent 16% of total workers' compensation claims, but a disproportionate 33% of total claim costs, over $20 billion (Katz, 2006; Webster & Snook, 1994). In industry, manual materials handling (MMH) jobs can cause excessive magnitude of loadings on workers' spinal structures, resulting in tissue damage (Brinckmann, Biggemann, & Hilweg, 1989; Gallagher, Marras, Litsky, & Burr, 2005); and hence increase the risk of WLBP in workplaces (Hoogendoorn et al., 2000; Marras, Ferguson, Lavender, Splittstoesser, & Yang, 2014; Thiese et al., 2014). To reduce the potential impact of MMH on workers' health, the National Institute for Occupational Safety and Health (NIOSH) has published guidelines for the industry to design and evaluate the physical demands associated with jobs that involve manual lifting and lowering of weights (NIOSH, 1981; Waters, Putz-Anderson, Garg, & Fine, 1993). Unfortunately, one frequent complaint of the NIOSH approach, the Revised NIOSH Lifting Equation (RNLE), has been the lack of capability to directly evaluate one-handed lifting (Marras & Davis, 1998). In the guide, "Risk Estimation for Musculoskeletal Disorders in Machinery Design", published by the European Trade Union Technical Bureau for Health and Safety (TUTB) (Ringelberg & Koukoulaki, 2003), an additional multiplier dedicated to "one handed operation" (OM = 0.6) was added to the original NIOSH approach to calculate the recommended weight limit (Waters et al., 1993). However, no reference was provided regarding the establishment of this one-handed lifting multiplier. In addition, to the authors' knowledge, nearly two decades later, there still is a lack of literature evaluating its performance and effectiveness in evaluations of one-handed lifting. Meanwhile, one-handed lifting has received little attention in both epidemiological and biomchanical research (Arjmand, Plamondon, Shirazi-Adl, Parnianpour, & Larivière, 2012; Ferguson, Gaudes-MacLaren, Marras, Waters, & Davis, 2002; Kingma, Faber, & van Dieën, 2016; Marras & Davis, 1998), compared to the well-studied two-handed lifting (Rajaee, Arjmand, Shirazi-Adl, Plamondon, & Schmidt, 2015). One possible reason could be the lack of input from the industry perspective regarding the actual one-handed lifting being performed by the workers. Previous surveys of industrial MMH jobs have only reported findings on the two-handed lifting and the associated RNLE variables (Ciriello & Snook, 1999; Ciriello, Snook, Hashemi, & Cotnam, 1999; Dempsey, 2003). Although one-handed lifting is reportedly common in workplaces (Ferguson et al., 2002; Marras & Davis, 1998), there is no objective survey of the jobs involving one-handed lifting and comprehensive descriptions of the associated job physical exposure.

The objective of this study was to provide objective survey of the MMH jobs, especially the ones involving one-handed lifting, performed by the US manufacturing workers, and comprehensively measure the associated job physical exposures. In addition, this study also aimed to compare three different methods proposed to handle one-handed lifting using RNLE approach.

METHODS

Population

This research is a cross-sectional study of the baseline survey of job characteristics and measurement of job physical exposures from the ***BackWorks Study*** cohort. The ***BackWorks Study*** cohort and data collection methods have been previously described (Garg et al., 2013). Workers were recruited from 30 diverse production facilities in the states of Wisconsin, Illinois, Texas, and Utah. The job tasks were primarily manual materials handling. Employer paid workers regular wages, and respondents were not given additional incentives for participation. Eligible participants were (a) at least 18 years of age, (b) able to give informed consent, (c) without plans to retire or leave their employer within 4 years, (d) able to speak either English or Spanish, and (e) free of major limb deformities and/or substantial amputations.

Job physical exposure data

Job physical exposure data were collected at the facilities of the participating companies by the Job Exposure Assessment Team (Garg et al., 2013). Job physical exposure data were measured at the subtask level. By definition, a worker performed one job in a workday, which may consist one or more tasks. A task may have one or more subtasks. And a subtask was defined as a manual lifting/lowering activity with a unique combination of biomechanical stressors, which provided first-hand, unprocessed information regarding an individual worker's exposure to job physical demands. Quantitative measurements of biomechanical stressors included: (a) object weights (W), (b) horizontal hand locations for each hand (H), (c) vertical hand locations for each hand (V), (d) trunk flexion and/or extension angles (TF), (e) trunk lateral bending angles (TLB), (f) trunk twisting angles (A), at the origin and destination of lifting/lowering, (g) travel distance (D), (h) hand-to-object coupling, (i) significant control at destination, (j) duration of the manual lifting/lowering subtask, and (k) frequency of the manual lifting/lowering subtask. Participating workers were revisited every three months to determine possible changes in physical exposure due to job changes.

Handling one-handed lifting

In this study, a one-handed lifting (OHL) subtask was defined as a scenario in which a worker was observed using only one hand to manually lifting/lowering an object at either origin or destination of the subtask, or both, compared to the two-handed lifting in which a worker should always use two hands during the whole process. For each subtask, the measured biomechanical stressors were used to derive respective RNLE variables. For a two-handed lifting (THL) subtask, the associated frequency independent lifting index (FILI) was calculated in accordance with the NIOSH manual (Waters et al., 1993). For a one-handed lifting subtask, the associated FILI was calculated by three methods; (a) do nothing and assign "not available" status (NA) to the corresponding subtask, strictly following the NIOSH manual (Waters et al., 1993); (b) apply standard NIOSH approach, treating one-handed lifting as two-handed (i.e., assign no weight to the none-helping hand; **FIRWL** and **FILI**); and (c) follow the TUTB guideline by assigning "one handed operation" multiplier (OM = 0.6) to the standard NIOSH equation to calculate the Recommended Weight Limit (RWL) as **FIRWL.one** and the subsequent **FILI.one** (Ringelberg & Koukoulaki, 2003). In addition, for each worker, the summation of the lift frequency associated with one-handed lifting subtasks was divided by the total frequency of all subtasks per task to represent the proportion of the one-handed lifting within a given task. Subsequently, similar proportion data were calculated at the job level.

Physical exposure assignment at the worker level

Due to the lack of guidance in the literature for assigning physical exposure at the worker level, this study used multiple measures, including (a) at the **subtask** level, the frequency independent RWLs (FIRWLs), FILIs; (b) at the **task** level, minimum FIRWL, peak FILI, and composite lifting index (CLI); and (c) at the **job** level, peak FILI, time-weighted-average CLI, peak CLI, and cumulative lifting index (CULI), based on the three proposed approaches to handle one-handed lifting, respectively. Peak FILI and peak CLI represent, respectively, the peak physical demands of subtasks and tasks performed by a given worker, as past studies have shown that the peak demands of a job are more predictive of LBP than the average physical demands of a job (Garg, Boda, et al., 2014). CULI represent the overall job physical demands. When summarizing the subtask level physical exposure to the task level, the proportion of lift frequency associated with one-handed lifting to the total lifting frequency within a given task was calculated (i.e., Task Proportion of Handedness). A similar proportion value (Job Proportion of Handedness) was also calculated when summarizing task level physical exposure to the job level.

Statistical analyses

Key analytic objectives of this study included: (a) Descriptive statistics of the job characteristics (i.e., biomechanical stressors) measured from the one-handed lifting subtasks, including mean and standard deviation, (b) Comparisons of the job characteristics between two-handed lifting and one-handed lifting, (c) Comparisons of the demographics of the workers with and without the component of one-handed lifting, and (d) Descriptions and Comparisons of the impact of the three proposed approaches handling one-handed lifting on the job physical exposure assessment at each level (i.e., subtask, task, and job). Independent-samples t tests, and/or Wilcoxon rank-sum tests were used to make comparisons of the worker demographics and job physical exposure among workers with and without the component of one-handed lifting, depending on the distribution of the data. Chi-square tests were used to analysis categorical variables. Paired-sample t tests and/or Wilcoxon signed-rank tests were used to make comparisons regarding the impact of the three proposed approaches handling one-handed lifting on the job physical exposure assessment at each level. All statistical analyses were conducted using R statistical software for Mac OS (R-64 version 3.5.3, The R Foundation for Statistical Computing, Vienna, Austria). Statistical significance was at p value < 0.05.

RESULTS

A total of 22874 lifting or lowering subtasks, 1359 tasks, and 713 jobs were observed and measured among a group of 623 workers. Most workers (n = 547; 88%) performed only one job. About 10% of workers (n = 63) performed two jobs. A small fraction of workers (≈ 2%) performed more than two jobs. In addition, more than half of the workers (≈ 54%) had job rotations (i.e., multi-task job) during their daily work shift.

In terms of prevalence, among all observed subtasks, one-handed lifting accounted for a very small portion (< 10%, Figure 1). Specific job physical exposure data revealed that, at the subtask level (Table 1), when lifting with both hands, workers dealt with much heavier objects (i.e., 24 pounds), compared to the ones during one-handed lifting (i.e., 12 pounds). During two-handed lifting, the objects were closer to the workers' bodies (i.e., smaller H), but lower to the ground (i.e., smaller V) and required longer travel distance (i.e., greater D). In addition, workers, when lifting with both hands, had more trunk flexion (i.e., higher TF) but less twisting (i.e., lower A) and less lateral bending (i.e., lower TLB). On the other hand, one-handed lifting was performed more frequently but less duration. Since RNLE variables were derived from the job characteristics mentioned above, similar patterns were also observed accordingly. When TUTB guideline was followed, the differences in FIRWL and FILI became more substantial. It should be noted that although some of these differences were significant, the actual magnitude might not be material or biologically plausible. These differences may be attributed to the uniqueness of this specific sample.

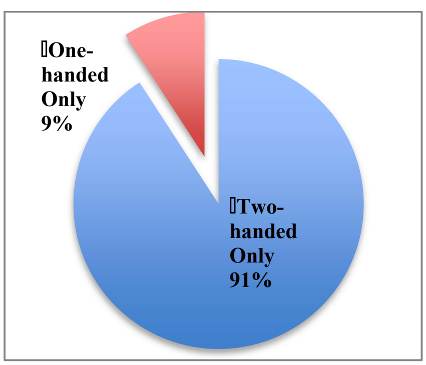

Figure 1. Handedness at the subtask level

	One-handed N = 2097 Mean±SD	Two-handed N = 20777 Mean±SD	P value
W (lb)	12.07±8.68	24.29±13.48	***< 0.001***
D (inch)	13.09±12.61	13.82±12.12	***0.009***
Max A (degree)	14.02±12.22	7.12±10.45	***< 0.001***
Max TF (degree)	27.74±22.66	33.93±27.54	***< 0.001***
Max TLB (degree)	2.84±4.91	0.99±2.81	***< 0.001***
At origin			
H (inch)	19.17±5.63	17.59±4.85	***< 0.001***
V (inch)	36.53±11.67	35.51±12.21	***< 0.001***
TF (degree)	18.26±20.78	24.24±25.65	***< 0.001***
A (degree)	9.38±10.78	4.88±8.93	***< 0.001***
At destination			
H (inch)	19.11±6.48	18.49±4.75	***< 0.001***
V (inch)	39.13±14.12	38.60±14.03	0.100
TF (degree)	19.63±19.57	21.01±23.35	***0.011***
A (degree)	9.22±10.73	4.12±8.35	***< 0.001***
Frequency (per min)	0.18±0.37	0.14±0.47	***< 0.001***
Duration (second)	1.72±0.67	1.75±0.55	***0.006***
RNLE variables			
HM	0.54±0.17	0.52±0.12	***< 0.001***
VM	0.89±0.09	0.88±0.07	***< 0.001***
DM	0.97±0.05	0.96±0.05	***< 0.001***
AM	0.96±0.04	0.98±0.03	***< 0.001***
FIRWL	22.72±8.01	22.46±6.38	**0.076**
FIRWL.one	14.12±4.87	22.46±6.38	***< 0.001***
FILI	0.63±0.53	1.18±0.78	***< 0.001***
FILI.one	1.01±0.86	1.18±0.78	***< 0.001***

Table 1. Job physical exposure at the subtask level

At the task level (Figure 2), a majority of tasks involved only two-handed lifting (n = 1010), followed by those with both one-handed and two-handed lifting (i.e., mixed-handed; n = 331). Only 1% of tasks (n =18) involved only one-handed lifting. With respect to one-handed lifting (OHL) component, only a small fraction of tasks (n = 100; 7%) had at least 50% of total lift frequency. When comparing the three methods handling one-handed lifting, the differences in both CLI (Table 2) and peak FILI (Table 3) were found significant among these tasks with at least 50% one-handed lifting component. In general, applying TUTB guideline yielded higher index values compared to the other two methods. For the rest of the tasks, results derived from these three methods were not statistically different.

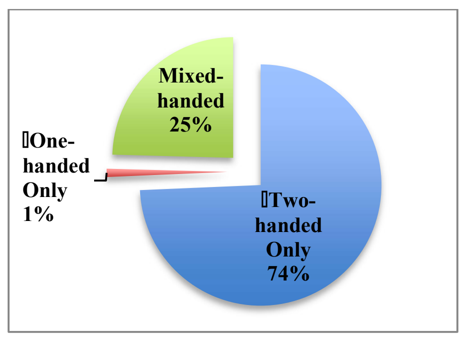

Figure 2. Handedness at the task level

OHL	N	Excluding	Assumed as THL	TUTB Guideline	P value
⩽ 10%	1100	2.07±2.00	2.07±2.01	2.10±2.04	0.919
< 25%	1165	2.08±1.96	2.08±1.96	2.11±2.00	0.892
< 50%	1259	2.04±1.14	2.07±1.97	2.11±2.02	0.609
⩾ 50%	100	1.68±1.05	1.83±1.32	2.46±1.81	***0.001***

Table 2. CLI at the task level with respect to OHL proportion

OHL	N	Excluding	Assumed as THL	TUTB Guideline	P value
⩽ 10%	1100	1.56±1.13	1.56±1.13	1.59±1.17	0.850
< 25%	1165	1.58±1.11	1.59±1.11	1.61±1.14	0.830
< 50%	1259	1.56±1.10	1.56±1.10	1.60±1.13	0.546
⩾ 50%	100	1.48±0.91	1.38±0.90	1.83±1.18	***0.005***

Table 3. Peak FILI at the task level

At the job level (Figure 3), most jobs involved only two-handed lifting (n = 424), followed by those involved mixed-handed (n = 280). There were 9 one-handed lifting jobs (i.e., OHL proportion = 100%; zero two-handed lifting proportion across all associated tasks). A majority of jobs had OHL proportion less than 50% (n = 615), with less than 15% of jobs (n = 98) had at least 50% or more. When comparing the three methods handling one-handed lifting, the differences in CULI (Table 4), peak CLI (Table 5), and time-weighted-average CLI (Table 6) were found significant among these jobs with at least 50% one-handed lifting component. In general, applying TUTB guideline yielded higher index values compared to the other two methods. For the rest of the jobs, results derived from these three methods were not statistically different. In addition, regardless of one-handed lifting proportion, there was no statistical significance in peak FILI resulted from all three methods (Table 7).

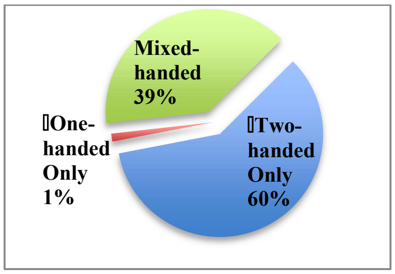

Figure 3. Handedness at the job level

OHL	N	Excluding	Assumed as THL	TUTB Guideline	P value
⩽ 10%	494	2.96±2.49	3.08±2.59	3.10±2.58	0.635
< 25%	538	2.93±2.40	3.07±2.51	3.09±2.50	0.510
< 50%	615	2.87±2.31	3.06±2.45	3.10±2.46	0.208
⩾ 50%	98	2.11±1.27	2.58±1.57	2.74±1.50	***0.010***

Table 4. CULI at the job level with respect to OHL proportion

OHL	N	Excluding	Assumed as THL	TUTB Guideline	P value
⩽ 10%	494	2.96±2.49	2.97±2.49	3.03±2.53	0.891
< 25%	538	2.93±2.40	2.95±2.41	3.01±2.45	0.861
< 50%	615	2.87±2.31	2.93±2.36	3.01±2.42	0.592
⩾ 50%	98	2.11±1.27	2.28±1.42	2.73±1.80	***0.015***

Table 5. Peak CLI at the job level

OHL	N	Excluding	Assumed as THL	TUTB Guideline	P value
⩽ 10%	494	2.76±2.46	2.77±2.46	2.83±2.51	0.893
< 25%	538	2.70±2.39	2.72±2.39	2.77±2.44	0.865
< 50%	615	2.60±2.31	2.66±2.36	2.74±2.42	0.611
⩾ 50%	98	1.64±1.05	1.77±1.12	2.09±1.27	***0.027***

Table 6. Time-weighted-average CLI at the job level

OHL	N	Excluding	Assumed as THL	TUTB Guideline	P value
⩽ 10%	494	2.02±1.19	2.02±1.19	2.07±1.25	0.739
< 25%	538	2.03±1.16	2.03±1.16	2.08±1.21	0.722
< 50%	615	2.02±1.14	2.04±1.14	2.10±1.19	0.475
⩾ 50%	98	1.87±1.16	1.82±1.13	2.09±1.22	0.240

Table 7. Peak FILI at the job level

DISCUSSION

This study is among the first few to provide objective survey of the MMH jobs, especially the ones involving one-handed lifting, performed by the US manufacturing workers. The current findings indicated vast difference in terms of the occurrence of one-handed lifting in manufacturing industry. Based on different level of job physical exposure measurement (i.e., subtask, task, and job), the occurrence of one-handed lifting varied from less than 10% at the subtask level to about 40% at the job level. Therefore, the current results are in partial agreement with previous authors reporting that one-handed lifting may be common in industry (Marras & Davis, 1998). On the other hand, previous studies have shown that the job physical exposure varied across different industries with heavy MMH activities (Tang et al., 2018). For example, workers in distribution centers are likely to handle a variety of products, while workers in manufacturing or fabrication industry are expected to handle a fixed amount of parts and tools. In addition, the current findings also agree with previous surveys on two-handed lifting jobs in primarily manufacturing and distribution sectors reporting large variations in job physical exposures (Ciriello and Snook, 1999; Ciriello, Snook, Hashemi, and Cotnam 1999; Dempsey, 2003).

Since this study began measuring job physical exposures at the very basic level (i.e., subtask), it was feasible to directly compare the biomechanical stressors between one-handed lifting and two-handed lifting. The current results revealed significant differences in almost every stressor measured, even though some differences might not be material or relevant. It was noted that during one-handed lifting, workers handled objects that weighted significantly lighter (i.e., 12 pounds; about half the weight) than the ones being handled during two-handed lifting. This weight falls in the range recommended by previous studies to maximize the work output of one-handed lifting (Mital, 1985). In addition, the current findings suggest that one-handed lifting does require greater trunk twisting and lateral bending but less trunk flexion, at both origin and destination. In terms of maximum trunk twisting and lateral bending observed, one-handed lifting resulted in greater magnitude compared to two-handed lifting (14° vs. 7° and 3° vs. 1°, respectively). From a biomechanical perspective, trunk motions in the lateral and transverse plane are likely to generate high spinal loading (Allread, Marras, and Parnianpour, 1996). As noted in the literature, NIOSH approach (i.e., RNLE), although added an asymmetry multiplier to address the need for asymmetric lifting, still lacks the ability to directly handle one-handed lifting (Marras & Davis, 1998). The current study evaluated and compared the outcomes of three methods handling one-handed lifting. Across the three methods, TUTB guideline, in general, provided higher score in each RNLE-derived index, due to the penalty assigned by the proposed multiplier (i.e., OM). Unfortunately, the current study did not find strong evidence suggesting the influence of one-handed lifting on an individual worker's job physical exposure, since the only significant differences were found among tasks and jobs with very high proportion of one-handed lifting (i.e., ≥ 50%). Therefore, the issues/influence associated with one-handed lifting may not be adequately addressed by a single multiplier, since there are other factors that may also contribute to the overall outcome, such as hand support (Kingma, Faber, van Dieën, 2016). In addition, it is important to investigate the spinal biomechanics involved in one-handed and asymmetric lifting and lowering activities, such as effective muscle lever arm and the actual physiological response of the spinal structures. Previous studies have reported the associations between body anthropometry and the geometry of lumbar spine and paraspinal muscles (Gungor et al., 2015a; Gungor et al., 2015b; Gungor et al., 2019; Tang et al., 2016; Tang et al., 2019). It may be feasible to study the characteristics of one-handed and asymmetric motions with similar anthropometric approach.

The main strengths of this study are the relatively large sample of manufacturing jobs and comprehensive job physical exposure measurement across subtask, task, and job level. These features should help better understand the occurrence and influence of one-handed lifting in workplaces. On the other hand, it has been noted that the use of just one hand to lift or lower an object may be at the discretion of the worker. In this study, job descriptions were not collected; therefore, it is not available to clarify how many workers were following the job descriptions and how many chose to use just one hand.

CONCLUSIONS

Based on this relatively large sample of manufacturing jobs, the occurrence of one-handed lifting varied according to the perspective of observation (i.e., subtask level vs. job level). At the subtask level, biomechanical stressors and RNLE variables are different between one-handed lifting and two-handed lifting, where at the task and job level, the differences may be more evident among the workers primarily performed one-handed lifting.

Acknowledgements

This publication was supported by the Grant or Cooperative Agreement Number, T42 OH008455, funded by the Centers for Disease Control and Prevention. Its contents are solely the responsibility of the authors and do not necessarily represent the official views of the Centers for Disease Control and Prevention or the Department of Health and Human Services.

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