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Review Article

Physiology Section

Potential Determinants of Manual Lifting: Validation of Ergonomic Assessment by Scoping Review Applying Meta-analysis Approach

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ABSTRACT

Introduction: Despite automation, manual load lifting is unavoidable in occupations like industry, healthcare, defence, etc. Ergonomics studies on manual lifting conducted across the globe explored few aspects of biomechanical and physiological responses. It was hypothesised that, 'holistic ergonomics approach' involving simultaneous recording of these responses under single study, would elucidate potential injury causing factors more effectively and results could be validated by applying meta-analysis technique of literature review.

Aim: To identify the potential determinants of manual lifting by applying multivariate statistics to existing data and correlate the results with determinants as per literature review applying meta-analysis.

Materials and Methods: Clustering and principal component analysis tools of factor analysis was applied on the data obtained under the pilot study (n=11) undertaken by same authors previously on manual lifting that assessed 26 dependent parameters simultaneously for load magnitudes (10 kg, 20 kg), lifting heights (floor-knuckle, knuckle-shoulder and floor-shoulder) and lifting frequencies (1 lift/min, 4 lift/min). Further, extensive scoping literature review on determinants of manual load lifting was done applying text mining tool of meta-analysis technique on R software platform using 921 Pubmed abstracts published between 1991 and 2018.

Results: Salient findings of factor analysis corroborated with that of scoping literature review. Accordingly, dependent variable 'Vertical Ground Reaction Force (VGRF)' and independent variable 'vertical height of lift' changed most significantly during manual lifting, showing significant positive correlations. Newton's third law of motion states that while bipedal standing/walking/running on floor, two forces (with three vector components) are acting upon a person: the force of gravity (downward force, equivalent to body weight) and the Ground Reaction Force (GRF, an equal upward force exerted by floor). However, while standing still at one place for lifting load, only the largest vector component of GRF, i.e., VGRF acts on the body (='body weight'+'load magnitude') through the vertical height of lift.

Conclusion: It may be concluded that 'vertical height of lift' and VGRF are possible indicators of injury potential of manual lifting. However, studies on larger sample size and meta-analysis of relevant full papers instead of abstracts need to be done in future.

Keywords: Data mining, Factor analysis, Lifting height, Vertical ground reaction force

INTRODUCTION

Despite automation, manual lifting of load is inherent to many occupations across the globe, including manufacturing industries, agriculture sectors, defence sector, health care services, construction workers and porters [1]. When undertaken without mechanical support, such tasks may put workers at great risk of injury or health disorder symptoms [2-6], increasing absenteeism, disability, economy and man hour loss. Load lifting capability of any population is directly related to anthropometric characteristics [7], muscular strength, endurance and flexibility. Lifting heavy load requires muscular strength and when the task is repetitive, muscular endurance is required which needs higher aerobic capacity of the worker. Muscular flexibility is important in protecting the individual against lower back pain and other overuse disabilities or injuries caused by manual lifting of load [8]. Thus, ergonomic assessment of Manual Lifting Tasks (MLT) is important for understanding the load lifting capacity of a given population, which varies with anthropometry, health and fitness level of concerned population. Therefore, adopting a holistic approach is required for ergonomically assessing the load lifting capability of Indian population for further customising such activities to minimise overuse injury potential. In addition, it is important to understand whether data on determinants of manual load lifting in Indian population have similarities with data existing globally in literature.

Numerous studies on ergonomic assessment of MLT exist across the globe that involve monitoring one or more dependent variables (kinematics, kinetics, Electromyography (EMG) and physiological parameters) indicating physical demands of these activities. Among independent variables, lifting height and weight are established as important determinants of Manual Material Handling (MMH) activities [9,10]. Past researches indicate that Maximum Acceptable Weight of Lift (MAWL) was influenced by age of lifter, lifting height, magnitude of load lifted manually and rate of lift [9,11-21]. Although researches on manual lifting have been carried out throughout the globe, they have reported a few aspects of manual load lifting. None of them have applied holistic ergonomics assessment approach, where maximum possible parameters pertaining to MLT could be investigated under a single study to elucidate how these parameters changed with respect to each other. With such approach it would be easier to identify the determinants of manual lifting indicating the physical workload and injury potential of MLT. Once such determinants were identified during human trials for a population, their role as potential marker of physical workload and overuse injuries needed to be validated by extensive review of literature pertaining to those determinants. However, such studies are rare in global literature and was so far not reported for Indian population. Therefore, a pilot study for holistic ergonomics assessment of manual load lifting (n=11) was carried out previously by Mondal K et al. They recorded 26 parameters (kinematics, kinetics, physiology and EMG responses) under a single study under same experimental conditions of lifting load magnitude, frequency and height of lift [22].

Following this, present study was designed to be carried out in two phases. First phase would involve applying multivariate statistics (factor analysis) on the data obtained under previously carried out holistic ergonomics study on MLT. Second phase would involve application of meta-analysis technique to conduct scoping review of literature on the 26 parameters pertaining to MLT that were dealt with in the first phase of the current study. Both scoping reviews and systematic reviews use meta-analyses techniques to provide replicable ways of summarising a group of published studies to address an important research issue. However, these techniques are distinct from each other and one needs to understand what research questions they can, and cannot address. Scoping review technique involves extensive literature search with exploratory or descriptive approach that is designed to map the literature around a particular topic which may comprise of several issues at a time, giving it a broader perspective. The results of scoping reviews may not only help to identify gaps in the existing literature, it may also identify areas where there may be sufficient depth of literature so that a systematic review may be done. Systematic reviews are intended to address a specific question by identifying and summarising all of the available research that has addressed the review question, pertaining to narrowed down issues, e.g., prevalence/incidence questions, aetiology, intervention efficacy, diagnostic test accuracy, etc. The systematic review involves extensive literature search in structured steps with multiple reviewers working in parallel to reduce the potential for bias. For each relevant study identified by the search, a formal extraction of data, including the effect size, and assessment of the risk of bias is performed. However, for both these processes, results from multiple studies are be combined using meta-analysis techniques, providing a summary effect size, and enabling the heterogeneity of effect among studies to be quantified and explored. Such evidence synthesis approaches may provide scientific input to evidence based, decision making and maybe useful for identifying lacunae in the literature to enhance the efficiency of future research in a topic area [23].

Research question in the context of current study pertaining to determinants of manual load lifting as studied by Mondal K et al. (2021) involved 26 dependent and 12 experimental conditions or independent determinants, thus expanding the horizons of investigation to a great extent. Therefore, it was understood that in the current scenario, conducting a scoping review would be more appropriate and the wide array of information would be subjected to meta-analysis and narrowed down to answer the research questions asked. It was hypothesised that the determinants of MLT identified for Indian population (first phase) would corroborate with those determinants reported by past studies carried out elsewhere on similar populations (second phase). Current study, therefore, had two objectives to attain:

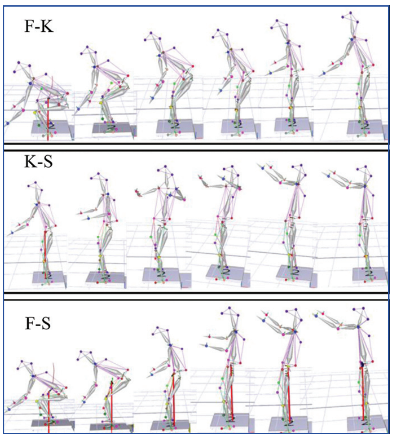
- To identify the dependent determinants of MLT which changed significantly for each of independent determinants using multivariate statistics on existing manual load lifting data
- To validate the results obtained under first objective of the present study by reviewing past studies on manual load lifting applying meta-analysis technique.

MATERIALS AND METHODS

Present study used the data already collected under a pilot study conducted by Mondal K et al. (2021) [22]. As no human trial was conducted under the current study, no permission from Institution's Ethics Committee was required.

Experimental Protocol (Mondal K et al., 2021)

Institutional Ethics Committee first approved experimental protocol [Ref. No. IEC/DIPAS/D-1/2 dated 08 December 2015] in accordance to Helsinki protocol (1964). Accordingly, informed consent was signed by each participant. The study involved physically fit and active Indian male urban students (n=11) with mean±SD age, height, weight and maximum oxygen consumption (VO_2max) as 24.2±2.23 years, 174.5±3.04 cm, 72.7±8.72 kg, and 38.4±3.96 $mL.min^{-1}.kg^{-1}$, respectively. Parameters pertaining to realtime kinematics, kinetics, surface electromyography and physiological measurements were collected during manual lifting of loads (10 and 20 kg) through three lifting heights Floor to Knuckle (F-K), Knuckle to Shoulder (K-S) and Floor to Shoulder (F-S) and two lifting frequencies (1 $lift.min^{-1}$ and 4 $lifts.min^{-1}$). Total number of 30 trials performed by each volunteer comprised of three trials for 1 $lift.min^{-1}$ and two trials for 4 $lifts.min^{-1}$. Five minutes resting pause was given after each trial [Table/Fig-1]. Videography for each trial was done and images were extracted at different positions and analysed to get 2D prediction biomechanics (kinematics and kinetics) parameters. For each parameter, "three way repeated measure Analysis of Variance (ANOVA)" was done, followed by Bonferroni post hoc test for the pairwise comparison of main effect within group using Statistical Product and Service Solutions IBM® (SPSS) version 21(M/s IBM Corp., USA). A value of $p \leq 0.05$ was considered to be statistically significant. Few [Table/Fig-2-5] from Mondal K et al. (2021) are included in the methodology of current paper for better understanding of the parameters used with an overview of salient findings of the previous study that forms

Height/Vertical Distance	Weight	Frequency	Combination	Trial nos. (Lift count×Repetition)	Sequence of events
Floor to Knuckle (F-K) 0.72 m	10 Kg	1 lift/min	FK10K1	3 (1×3)	
		4 lift/min	FK10K4	2 (1×2)	
	20 Kg	1 lift/min	FK20K1	3 (1×3)	
		4 lift/min	FK20K4	2 (1×2)	
Knuckle to Shoulder (K-S) 0.69 m	10 Kg	1 lift/min	KS10K1	3 (1×3)	
		4 lift/min	KS10K4	2 (1×2)	
	20 Kg	1 lift/min	KS20K1	3 (1×3)	
		4 lift/min	KS20K4	2 (1×2)	
Floor to Shoulder (F-S) 1.41 m	10 Kg	1 lift/min	FS10K1	3 (1×3)	
		4 lift/min	FS10K4	2 (1×2)	
	20 Kg	1 lift/min	FS20K1	3 (1×3)	
		4 lift/min	FS20K4	2 (1×2)	
Total number of trials				30	

[Table/Fig-1]: Details of the manual lifting tasks with their skeletal images of activity postures (n=11) performed under Mondal et al., (2021) [22].
Floor-Knuckle+10 Kg+1 $lift.min^{-1}$ (FK10K1); Floor-Knuckle+20 Kg+1 $lift.min^{-1}$ (FK20K1); Floor-Knuckle+10 Kg+4 $lifts.min^{-1}$ (FK10K4); Floor-Knuckle+20 Kg+4 $lifts.min^{-1}$ (FK20K4); Knuckle-Shoulder+10 Kg+1 $lift.min^{-1}$ (KS10K1); Knuckle-Shoulder+20 Kg+1 $lift.min^{-1}$ (KS20K1); Knuckle-Shoulder+10 Kg+4 $lifts.min^{-1}$ (KS10K4); Knuckle-Shoulder+20 Kg+4 $lifts.min^{-1}$ (KS20K4); Floor-Shoulder+10 Kg+1 $lift.min^{-1}$ (FS10K1); Floor-Shoulder+20 Kg+1 $lift.min^{-1}$ (FS20K1); Floor-Shoulder+10 Kg+4 $lifts.min^{-1}$ (FS10K4); Floor-Shoulder+20 Kg+4 $lifts.min^{-1}$ (FS20K4)

a basis for current review. For detailed information the published paper may be referred [22]. Respective significance levels of 26 dependent variables studied across different independent variables are given in [Table/Fig-2] [22]. Parameters which exhibited pairwise significant responses and their levels of significance are given in [Table/Fig-3,4], respectively. Out of 26 dependent variables, 12 variables for lifting weight, all variables for lifting height and five variables for lifting frequencies showed significant changes (p-value ≤0.05; [Table/Fig-3]. Further it was observed that only Vertical Ground Reaction Force (VGRF) showed significant variation across all independent variables of weight F(1,10)=78.854, p-value=0.001, height F(1.279,12.794)=44.349, p-value=0.001 and frequency F(1,10)=9.510, p-value=0.01 [Table/Fig-3-5].

Study Protocols for Current Multivariate Analysis and Scoping Review

i) Factor analysis: Principle Component Analysis (PCA) and clustering

Prior to factor analysis, sample adequacy test of Kaiser-Meyer-Olkin (KMO) measure and Bartlett's test of sphericity were done. The KMO measure of sampling adequacy is a statistic that indicates the proportion of variance in the concerned variables that might be caused by underlying factors. Sample adequacy is a point where facts about the sample are reasonable approximation about the population and the sample size can be said to be adequate. High values of KMO (0.8 to 1.0) indicates that factor analysis may be useful for the concerned data and that the sampling is adequate. If KMO value is less than 0.6, it indicates that sampling is not adequate and remedial actions need to be applied. Bartlett's test of sphericity compares an observed correlation matrix with identity matrix. It tests homogeneity of variance across the samples and is used to check if there was a certain redundancy between the variables that could be summarised with a few number of factors. Significance level for Bartlett's test below 0.05 indicates that there is substantial correlation in the data [24,25].

Factor analysis is a technique to reduce a large number of variables into fewer numbers of factors. This technique extracts maximum common variance from all variables and puts them into a common score. Factor loading is basically the correlation coefficient for the variable and factor, indicating the variance explained by the variable on that particular factor. This technique factorises a massive matrix with more than two components into new dimensions known as eigen vectors which are defined dimensions with specific eigen values that are scalar quantities. These eigen values or 'characteristic roots' show a proportion of the variance explained by one particular factor out of the total variance. Thus factor analysis is applied on the multidimensional experimental data for identifying the number of variables. The factor scores or the component scores of all rows and columns are used as indices of all variables and can be subjected to further analysis. This score can be standardised as factor score by multiplying by a common term. Whatever further analysis is done, it is assumed that all variables will behave as factor scores and will move. According to the Kaiser criterion, variable having eigen value greater than one is a factor and if it is less than one, it should not be considered as a factor.

Principle Component Analysis (PCA), most commonly used procedure of factor analysis in research, was performed on same platform to find out unique determinants of manual lifting. Using this method, maximum variance was extracted and put into the first factor. After removing the variance explained by the first factor, it

	Weight			Frequency			Height		
Parameters	df	F-value	p-value	df	F-value	p-value	df	F-value	p-value
Neck angle	--	--	--	--	--	--	2,20	6.652	0.006
Forearm angle	--	--	--	--	--	--	2,20	3.440	0.05
Upper arm angle	--	--	--	--	--	--	2,20	7.147	0.005
Leg angle	--	--	--	--	--	--	1.360, 13.596	4.061	0.05
TCF	1,10	131.523	0.001	--	--	--	2,20	27.586	0.001
CF-L	1,10	1011.362	0.001	--	--	--	1.352, 13.517	28.689	0.001
TSF	1,10	92.297	0.001	--	--	--	2,20	70.340	0.001
SF-L	1,10	1412.970	0.001	--	--	--	2,20	112.325	0.001
Trunk angle	1,10	6.125	0.03	--	--	--	2,20	435.882	0.001
Elbow angle	1,10	6.812	0.03	--	--	--	2,20	3.331	0.05
Knee angle	1,10	5.179	0.04	--	--	--	2,20	126.241	0.001
Ankle angle	--	--	--	1,10	11.138	0.008	2,20	66.938	0.001
VGRF	1,10	78.854	0.001	1,10	9.510	0.01	1.279,12.794	44.349	0.001
Moment A-P	--	--	--	1,10	7.449	0.02	1.90,11.901	7.033	0.01
Work	1,10	161.546	0.001	--	--	--	2,20	10.070	0.01
Power	1,10	221.849	0.001	--	--	--	2,20	16.828	0.001
R-Gastrocnemius	1,10	4.722	0.005	--	--	--	2,20	6.406	0.007
L-Gastrocnemius	--	--	--	--	--	--	2,20	8.489	0.002
R-Hamstring	1,10	5.599	0.04	--	--	--	2,20	12.504	0.001
L-Hamstring	--	--	--	--	--	--	2,20	13.740	0.001
R-Erector Spinae	--	--	--	--	--	--	2,20	8.489	0.002
L-Erector Spinae	--	--	--	--	--	--	2,20	10.297	0.001
R-Trapezius	--	--	--	--	--	--	2,20	11.095	0.001
L-Trapezius	--	--	--	--	--	--	2,20	13.353	0.001
VO_2	--	--	--	1,10	7.838	0.02	2,20	31.950	0.001
RWL	--	--	--	1,10	7.882	0.02	2,20	27.633	0.001

[Table/Fig-2]: Levels of significance for kinematics, kinetics, EMG and physiological responses during MLT with three independent variables (load magnitudes, frequencies of lift and heights of lift) by Mondal et al., (2021) [22].

p-values given by analysis of variance tests, SPSS for windows, version 21; Non-significant values were not tabulated and marked as "—"; TCF: Total compressive force; CF-L: Compressive force due to load; TSF: Total shearing force; SF-L: Shearing force due to load; VO_2: Oxygen consumption; RWL: Relative workload

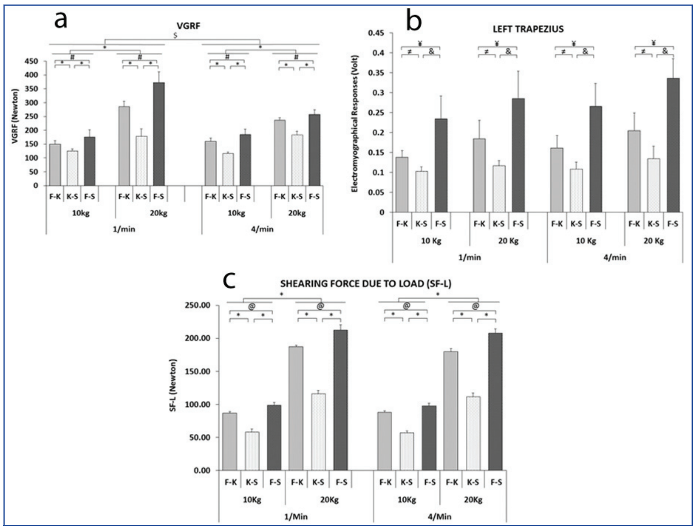
Parameters	p-value		
	F-K vs F-S	F-K vs K-S	K-S vs F-S
Neck angle	0.02	--	--
Forearm angle	--	--	0.04
Upper arm angle	--	0.0001	0.001
Leg angle	--	--	--
TCF		0.0001	0.001
CF-L	0.0001	--	0.0001
TSF	--	0.0001	0.0001
SF-L	0.01	0.0001	0.0001
Trunk angle	0.0001	--	0.0001
Elbow angle	0.05	--	--
Knee angle	--	0.0001	0.0001
Ankle angle	--	0.0001	0.0001
VGRF	0.03	0.0001	0.0001
Moment A-P	0.03	--	0.05
Work	--	--	0.02
Power	0.005	--	0.002
R-Gastrocnemius	--	--	0.02
L-Gastrocnemius	0.05	--	0.002
R-Hamstring	0.04	--	0.001
L-Hamstring		0.03	0.001
R-Erector Spine	0.04	--	0.02
L-Erector Spine	--	--	0.003
R-Trapezius	--	--	0.001
L-Trapezius	0.04	0.03	0.004
VO_2	0.0001	--	0.002
RWL	0.0001	--	0.005

[Table/Fig-3]: Levels of significance for lifting at different heights as observed in under Mondal et al., (2021) [22].
p-values given by Bonferroni post hoc test, SPSS for windows, version 21; Non-significant values were not tabulated and marked as "—". TCF: Total compressive force; CF-L: Compressive force due to load; TSF: Total shearing force; SF-L: Shearing force due to load; VO_2: Oxygen consumption; RWL: Relative workload

Height of lift	Load lifted	Frequency of lift
VGRF	Trunk angle	Ankle Angle
EMG of L-trapezius	Elbow angle	VGRF
SF-L	Knee angle	Moment A-P
--	VGRF	VO_2
--	Work	RWL
--	Power	--
--	EMG of R-Gastrocnemius	--
--	EMG of R-Hamstring	--
--	TCF	--
--	CF-L	--
--	TSF	--
--	SF-L	--

[Table/Fig-4]: Dependent determinants of manual lifting that significantly changed in pair-wise tests across three independent determinants studied by Mondal et al., (2021) [22].
Significantly changed variables by Bonferroni post hoc test are reported. With respect to height and frequency of lift non-significant blank cells were marked "—". TCF: Total compressive force; CF-L: Compressive force due to Load; TSF: Total shearing force; SF-L: Shearing force due to load; VO_2: Oxygen consumption; RWL: Relative workload

extracted maximum variance for the second factor and this process went on till the last factor. This technique removed dependency or redundancy in the data by dropping those features that contained the same information as given by other attributes so that the derived components were independent of each other. This approach reduced unnecessary features by creating or deriving new dimensions (or also referred to as components) that were linear combinations of original variables. This way, PCA converted a larger number of correlated variables (i.e., breaking down the data) into smaller sets of uncorrelated variables. A principal component of a data set is defined as the direction of the dataset explaining the highest variance, as implied by the eigen value of that component. The prominent features in tabular data matrix used under current study was extracted using PCA that yielded confirmatory identification of main determinants of manual load lifting [26-28].



[Table/Fig-5]: Changes in dependent variables presented in x-axis [VGRF(A), L-Trapezius(B) and SF-L (C)] with variations in independent variables given in Y-axis (lifting heights (F-K, K-S and F-S), lifting frequencies (1 and 4 lifts.min-1).
*p=0.0001; #p=0.002; @p=0.01; $p=0.03; &p=0.004; ¥p=0.04 (Refer Mondal et al., (2021) [22])

Thereafter, the outcome of PCA was subjected to hierarchical clustering of variables for finding out variations in the data using "pheatmap" and "factoextra" library packages in R software. Pheatmap is a function of R package for drawing clustered heatmaps that allows to aggregate the rows using 'k means' clustering if number of rows is too big for R package to handle (>1000), as was the case in current study. Factoextra package of R is an effective and user friendly tool to extract and visualise the results of exploratory multivariate data analyses like PCA from various packages. It also identifies the most important parts of the PCA results and highlights those rows/columns with quality representation on the factor map and their contributions to the principal dimensions [29,30].

ii) Text mining based meta-analysis

Text mining, that uses text data mining tool of meta-analysis is the process of transforming unstructured text into structured formats to identify meaningful patterns, trends and new information by applying advanced analytical techniques. These patterns and trends cannot be discovered by traditional data exploration methods because of the fact that there may be too much data or the inter-relationships of these data may be too complicated. These patterns and trends are communicated or expressed in various understandable forms using data visualisation techniques.

Present review involved gathering and presenting available research evidences related to titles and abstract screening of literature pertaining to manual load lifting using text mining tools. During different steps of carrying out meta-analysis, defined questions in form of research queries were addressed and text data from specific theme studies for the given time period was analysed. Thus, in order to validate the results of multivariate statistics under the current study, meta-analysis technique was successfully applied for reviewing literature of past three decades for identifying determinants manual load lifting. Different steps involved in current review is given below.

a) **Data preprocessing and extraction:** Data preprocessing in text mining is the process of transforming raw data into an understandable format, checking and improving the quality of data before subjecting it to machine learning algorithms. Therefore, in present context, main steps carried out were information retrieval (raw data collection based on pre defined set of queries and pre processing using subtasks like tokenisation and stemming for reducing sizes of indexing files) and Information Extraction (using subtasks like feature selection for identifying most contributing dimension and feature extraction for reducing dimensions). The raw data of our interest was extracted from the PubMed interface of 'R package'. The query design matrix [Table/Fig-6] was based on different experimental aspects of MLT with exclusion of articles related to "lifting in sports" and articles matching best with the filter 'human' were identified. Using R statistical environment, unified datasets of relevant articles from PubMed source were collected and the metadata was compiled on 18 January 2019. Article indexing was performed with medline ranker. Articles having non significant p-values >0.01 were eliminated at the initial stage and number of articles were further reduced applying box plot on the basis of p-values |log10| obtained from medline ranker. Articles that appeared as outliers above the 4^{th} quartile in the box plot were used for analysis [31]. Best matched outlier articles with significant p-value were considered and the articles dated back from 1991 and the publication time period was between the year 1991 and 18 January 2019.

S. No.	Variables of interest	Query design	No of unique articles in PubMed
1	VGRF	((((Vertical) AND ground) AND reaction) AND force) AND lifting) NOT Sports	536
2	SFL	(((shearing) AND force) AND lifting) NOT sports	25
3	F-K	(((floor) AND knuckle) AND lifting) NOT sports	14
4	F-S	(((floor) AND shoulder) AND lifting) NOT sports	21
5	K-S	(((knuckle) AND shoulder) AND lifting) NOT sports	27
6	MWL	((((manual) AND load) AND weight) AND lifting) NOT sports	181
7	L-Trapezius	((((left) AND trapezius) AND electromyography) AND lifting) NOT sports	144
Total Articles Unique article after redundancy elimination			948 921

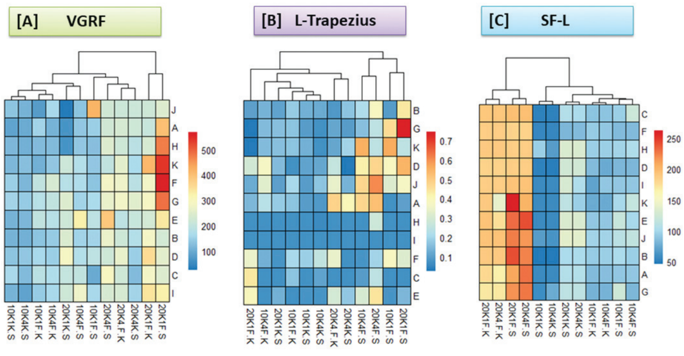
[Table/Fig-6]: Structured queries to collect the relevant scientific literature from PubMed for the keywords of interest related to manual lifting tasks conducted by Mondal et al., (2021) [22].

b) Presentation of text data: Multiple Multiple R based functions and packages were used to sort and subset the metadata. The abstracts as text data were exported in R software using "PubMedWordcloud" library package using get abstracts function [32]. Word clouds and bar charts were plotted with top 50 words and top 20 words respectively for all three decades starting from 1991.

RESULTS

i) Cluster analysis outcomes

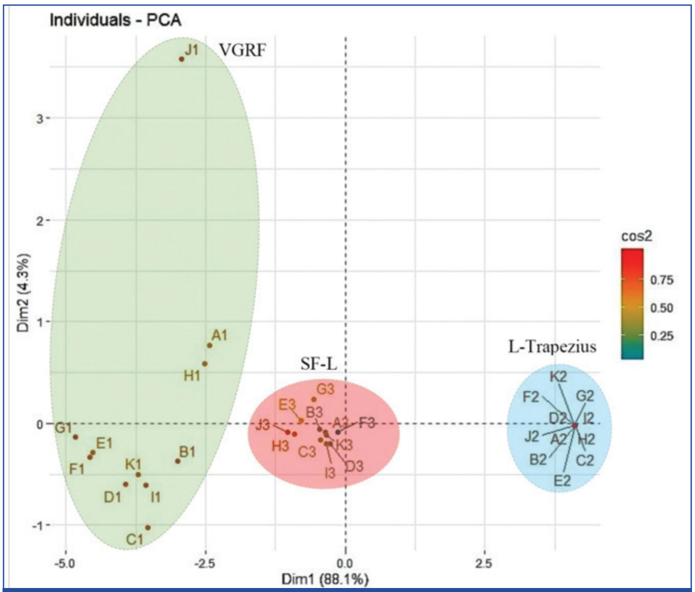
The study by Mondal K et al. reported that, out of three independent factors of MLT studied, 'lifting height' showed most significant responses with dependent factors VGRF, L-trapezius and SF-L [Table/Fig-4]. These variables were subjected to clustering under factor analysis technique for identifying significant determinant of MLT using R programming and clustering patterns of individual determinants were analysed [Table/Fig-7]. Classification of 12 experimental tasks was done using VGRF values. According to VGRF and SF-L based clustering, 'floor to knuckle' and 'floor to shoulder' with 20 Kg weight were classified together. Further, VGRF clustered 'knuckle to shoulder' with load of '20 Kg' and 'floor to shoulder' with load of '10 Kg' for lifting frequencies 1 lift/min and 4 lifts.min^{-1}, respectively. Values of L-Trapezius were inappropriate for classification of experimental tasks. Thus, ranking obtained in descending order was VGRF>SF-L>L-Trapezius, indicating VGRF as most important determinant of MLT.



[Table/Fig-7]: Clustering of values obtained for dependent variables VGRF, L-Trapezius and SF-L from each participant (n=11) are represented at top of the graph and labelled as A to K, respectively while the bottom of the cluster represented the manual lifting tasks carried out under Mondal et al., (2021) [22]. The maximum (red) and minimum (blue) values range of these variables are shown as bar graph. Intensity of dependent variables VGRF and SF-L readily classified the MLT given in two and three major groups as compared to L-Trapezius, respectively; These dependent variables were selected for clustering as they were found to be statistically significant for MLT in different lifting heights; VGRF: Vertical ground reaction force; SF-L: Shearing forces due to load

ii) Principal component analysis (factor analysis) outcomes

Responses of VGRF, L-Trapezius and SF-L during MLT [22] were subjected to principal component analysis. Sample adequacy measures were: KMO=0.76, χ^2=831.85, df=66, p-value <0.01. The KMO value >0.68 indicated factor analysis adequacy of current data. Highest variation in the PC1 axis (88.1%) was observed for VGRF as compared to SF-L and L-Trapezius in the PC2 axis (4.3%) [Table/Fig-8]. This indicated VGRF as most important determinant of MLT and indicator of injury potential of such tasks.

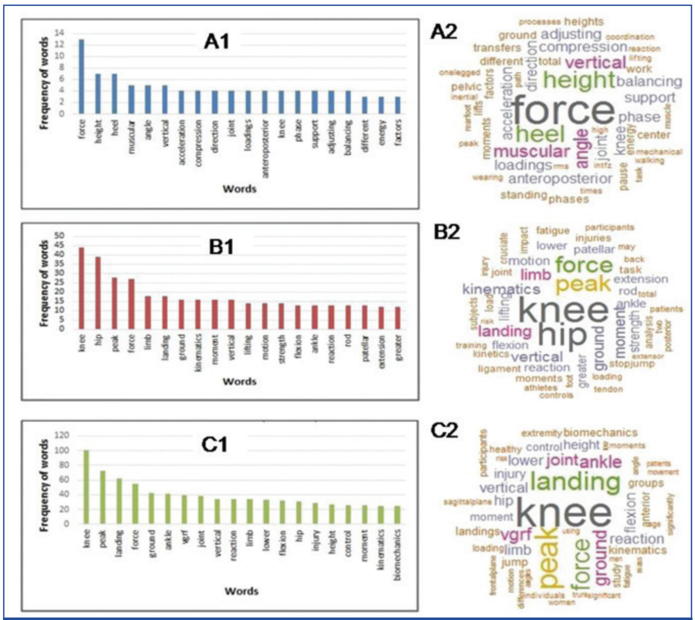


[Table/Fig-8]: Principal component analysis (PCA) of dependent variables VGRF (green broken lines), L-Trapezius (blue lines) and SF-L (Orange dotted lines) for participants (n=11) are presented (Refer Mondal et al., (2021) [22]). Circles with light green shade; light red shade; and aqua shade represent individual data of Vertical ground reaction force (VGRF), Shearing Force of Load (SF-L) and EMG of L-Trapezius (L-Trapezius); respectively

iii) Meta-analysis outcomes

Number of articles fetched by R programming from PMIDs with each query and total number of unique articles obtained after redundancy elimination are reported in [Table/Fig-6]. A total number of unique 921 PMIDs obtained was reduced to 109 articles by medline ranker which were statistically significant at the level of p-value <0.01. Out of these, 44 unique articles were outliers with most significant p and were selected for meta-analysis. Word cloud analysis showed 50 key words which ranked top in terms of frequencies in all three decades (1991-2000; 2001-2010 and 2011-2018). Most frequently used words in first decade (1991-2000) were "vertical" and "force". Keywords "vertical", "ground", "reaction" and "force" were most frequently used words in the decades 2001-2010 and 2011-2018;

also appearing among the top 20 frequently used key words in all the decades [Table/Fig-9].



[Table/Fig-9]: Representation of frequency distribution outcomes and word cloud analysis of abstracts obtained from Medline Ranker for three time periods 1991-2000 (A), 2001-2010 (B) and 2011-2018 (C).
The X- axis of the bar graphs (A1, B1 and C1) represent the top 20 keywords and respective Y-axis represent corresponding frequency values. Fig A2, B2 and C2 represent distribution of top 50 keywords from word cloud analysis. The font size and color of words indicated the intensity of their distributions. In all time periods, VGRF (violet color in C2) and the related terms vertical (Violet color in A2), force (green color in B2) and ground (violet color in C2) were found to dominate for all manual lifting tasks

DISCUSSION

Different studies in the past have discussed different aspects of Manual Lifting Tasks (MLT). Biomechanical approaches of assessing effects of MLT on back and spinal kinematics [14], full body kinematics [21], spinal kinetics and trunk muscular forces [33], lumber loading [34], segmental kinematics and ground reaction force [35], trunk and hip kinematics [36] and load acceleration and angular velocity [37] were observed. Also, frequently, electromyography (EMG) responses of different muscle groups [11,16,38,39] and physiological determinants [13,39-42] have been used to understand different aspects of MLT. Jorgensen MJ et al. (1999) used psychophysical technique to identify biomechanical and physiological variables associated with the decision of participants 'to change the weight of lift' while determining Maximum Acceptable Weight of Lift (MAWL). Therefore, trunk positions, velocities and accelerations were measured during lifting and spinal loading were computed in terms of moments and forces in three dimensions using an EMG assisted biomechanical model [38]. Many methods for evaluation of MLT exist in literature which assess such activities and may suggest how to ergonomically maintain the task demand within safe limits of the person's capability [43]. However, none of these studies used 'holistic ergonomics assessment approach' that would include simultaneously all possible determinants of MLT in a single study and therefore, could not point out one or more dependent determinant of MLT that would maximally help to assess the injury risk potential of the given lifting task. Over the years, practice has gradually evolved into 'holistic ergonomics' that fuses physiological, biomechanical and other related aspects of today's workplace together, thus expanding the horizon of authentic knowledge across wide range of ergonomics issues [44]. The study by Mondal K et al. (2021) applied this holistic ergonomics approach and reported 26 parameters related to manual load lifting under a single study [22].

Primary objective of current study involved advanced statistical treatment of this data obtained by Mondal K et al. (2021) in order to determine most important dependent and independent determinant of manual lifting that had highest injury potential in terms of physical workload. Once dependent and independent determinants were identified using clustering and principal component analysis techniques, the second objective of the current study was to validate the findings of the first objectives with the data available in literature. Now the questions that arose were, what type of review systematic or scoping, was required under such condition and how to go about it. Systematic reviews are resource intensive and more useful in replying queries pertaining to most applicable/suitable clinical practices or treatments in health care issues whereas, Scoping reviews are exploratory and typically address a broader question. They have a great utility in synthesising research evidence and are often used to categorise literature in terms of nature, features and volume.

According to Grant MJ and Booth A (2009) 'scoping reviews' are preliminary assessment of potential size and scope of available literature and aims to identify nature and extent of research evidence, sometimes including ongoing research and is used to highlight gaps or lacunae in the literature [44]. Having wider horizon, scoping reviews may be used to decide whether it would be useful to conduct a systematic review [45]. For conducting a scoping review, one needs to consider all aspects relating to a 'research topic or issue', rather than 'questions' based studies as done under systematic reviews. The process of searching the literature for relevant studies is same for both scoping and systematic reviews Thus, in the context of current study, conducting a scoping review to find out more about the body of evidence in area of 'manual lifting' seemed to be a better idea, aiming to maximise the sensitivity of the search for identifying relevant literature. Carrying out current review was important due to the fact that decisions about the utility of an intervention or the validity of a hypothesis cannot be based on the results of a single study as results typically vary from one study to the next. Rather, a mechanism was needed to synthesise data across studies. Narrative reviews on any subject are largely subjective and becomes difficult when there are more than a few studies involved. Meta-analysis, by contrast, applies objective formulae (much as one would apply statistics to data within a single study), and can be used with any number of studies. Thus this unique approach of the current study may provide insight to resolving such issues and may help in identifying and bridging the gap in literature [23].

Meta-analysis refers to the statistical analysis of the meta data collected from independent primary studies focused on the research topic, aiming to generate a quantitative estimate of the studied phenomenon. Goals of meta-analysis include assessing the strength of evidence available on a particular research question, determining whether an effect exists and if it exists, whether the effect is positive or negative and finally obtaining a single summary estimate of the effect. Current review was designed to collect information from huge number publications for identifying effective determinants of manual lifting. Meta-analysis was applied to collect the data produced by available research studies (tabular, text and photos) which could then be combined, quantified and analysed to obtain new insights. 'Text mining' or text data mining' tool of meta-analysis carries out the process of discovering information and structure from unstructured data, such as 'texts'. meta-analysis can be used to identify the common effect when the treatment effect (or effect size) is consistent from one study to the next. When the effect varies from one study to the next, meta-analysis may be used to identify the reason for the variation [45,46].

Novel aspect of the current study lies in the treatment of the responses of dependent variables from Mondal K et al. (2021) with factor analysis technique and applying meta-analysis approaches on literature available to identify potential injury determinant. The fact that multivariate statistical treatment results corroborated with meta-analysis outcomes brings out a point of convergence for various doctrines/opinions for understanding physical workload and injury potential of MLT [22].

Previously, Pinder ADJ and Boocock MJ (2014) considered meta-analysis to find out manual acceptable weight of lift from the frequency of lift [20]. Zadpoor AA and Nikooyan AA, (2012) used meta-analysis to find out the effects of lower extremity muscular fatigue on ground reaction forces [46]. Final outcomes of the meta-analysis of relevant literature is discussed below in terms of lifting height and VGRF:

Lifting height: An independent determinant of MLT

Manual lifting of load is one of the most common activities and form integral part of many occupations. Therefore, ergonomic assessment of manual lifting undertaken for different occupation is important for designing concerned operations [47]. Evaluation of MLT from the viewpoint of human safety dates back to early 1960s [42] and is continuing [19]. Meanwhile researches on this issue continued to understand different responses of MLT, viz., prediction and real time biomechanics, physiology, electromyography and psychophysiology [1,33,40,48-50], considering a few variables at a time. Current study reported that all 26 dependent variables showed overall significant effect [Table/Fig-2,3] with 'lifting height' variations. Thus, it can be stated that 'lifting height' had the ability to significantly affect the dependent variables and could be considered as a potential independent indicator of physical workload involved for assessment of MLT. Identifying such variables may help future researchers to categorise MLT according to the severity of injuries that could be caused by prolonged carrying out of such tasks.

VGRF: Dependent determinant of MLT

The 26 dependent determinants of MLT evaluated in Mondal K et al. (2021), including prediction and real time biomechanics, electromyography and physiological parameters, are listed in [Table/Fig-2] and [Table/Fig-3]. The meta-analysis on literature review conducted under current study indicated that these were the determinants of MLT reported by past studies also [19,50-52]. However, as none of the studies reported all 26 parameters, those past studies could not holistically determine which variable had highest injury potential in terms of physical workload. According to statistical analysis of the variables by Mondal K et al. (2021), out of 26 variables reported, only three variables for 'height of lift', 12 variables for 'weight of lift' and five variables for 'frequency of lift' showed significant variations between/within group independent variables [Table/Fig-3,5]. Fineberg DB et al., (2013) established that while using powered exoskeleton for weight lifting and carrying tasks, participants with varying weight, gait speed, and level of assist could be evaluated for the magnitudes of loading and gait mechanics by estimating the VGRF profile [50]. Similarly, results of the current study also indicates that VGRF could be the single most important variable that showed significant variations across all conditions of MLT [Table/Fig-3,5] and could be used to interpret the occupational risk of various MLT.

The U.S. Department of Health and Human services published a report in 1981, which gave in detail the work practice guidelines for manual lifting based on the epidemiological, biomechanical, physiological and psychological approaches. This report indicated that spinal forces played key role in interpreting the injury risk of MLT [40]. Chaffin DB and his colleagues frequently focused on 2D biomechanics prediction approaches, especially for assessing spinal force during manual lifting [47-49,51]. Along with VGRF, which showed significant variations across all the experimental independent variables in current study, L-Trapazius and SF-L were statistically significant across all the three lifting height conditions. Newton's third law of motion states that while bipedal standing/ walking/running on floor, two forces (with three vector components) are acting upon a person: the force of gravity (downward force, equivalent to body weight) and the Ground Reaction Force (GRF, an equal upward force exerted by floor). However, while standing still at one place for lifting load, only the largest vector component of GRF (Z-axis), i.e., VGRF acts on the body (='body weight'+'load magnitude') through the vertical height of lift. The trapezius muscle elevates, depresses, and retracts the scapula or the shoulder and plays vital role in preventing injury in overhead lifting of load. Shear forces associated with lifting may cause injury as they are unaligned forces generated by external force (load being lifted) that push one part of a body in one direction and another part of the body in the opposite direction [22].

Therefore, the present study considered these three variables (VGRF, L-Trapezius and SF-L, [Table/Fig-5] for PCA to identify which dependent variable was most frequently influenced by all the independent variables of MLT. Pheatmap showed that VGRF was the variable causing variations in the data across volunteers. Responses of VGRF to lifting height F-S was found to be dependent on lifting weights and frequencies as F-S did not make any cluster with either lifting weights or frequencies used in current study. Corroborating with the results of Mondal K et al. (2021), individual plot [Table/Fig-8] obtained from PCA indicated that VGRF was the variable that was maximally affected by MLT.

Significant correlation of VGRF with MLT

Pinder ADJ and Boocock MG (2014) considered text mining approach to predict the 'maximum acceptable weight of lift' using 'frequency of lift' as the independent variable [20]. Similarly, in this current paper, an attempt has been made to identify the significant dependent variables of MLT as reported by previous studies applying meta-analysis. Findings of meta-analysis conducted in present study corroborated with the findings of the literature review by Zadpoor AA and Nikooyan AA (2012) that used meta-analysis approach to find out effects of GRF on lower extremity muscular fatigue [46]. This review article stated that the impact of ground on human body during different physical activities provided the pathway in which musculoskeletal system got loaded. The GRF, especially the VGRF (vertical component), is the measure of musculoskeletal system loading at the contact with ground and may be 2-11 times the body weight of an individual. It was concluded that peak GRF and muscle loading were directly related to muscle fatigue. Under such conditions of elevated muscle fatigue, body's inherent capabilities to manage the impact by responses of lower body kinematics [53] got compromised which, eventually, increases the injury risks [49]. On similar lines, present study considered text mining approach which fetched 921 articles after redundancy elimination [Table/Fig-6] while every possible aspect of occupational manual lifting other than 'sports activities' were considered. A search criterion of 'human' was applied. 44 outlier articles were selected for further text analysis on the basis of 'p' values through Medline ranker. Significant articles were found between 1990 and 2018 and were categorised in three groups as per the decade of publication (1991-2000, 2001-2010 and 2011-2018). It was observed that the word 'force' was the most frequently used word and the words like "vertical", 'ground' and 'force' were within top 50 words [Table/Fig-9: A1 and A2] in the decade 1991-2000. The observations for decade 2001-2010 indicated that the word 'force' was found to be within top 5 words and the words in combinations out of "vertical", 'ground', 'reaction' and 'force' were found to be within top 50 words [Table/Fig-9: B1 and B2]. Interestingly, the words "vertical", 'ground', 'reaction' and 'force' were found to have appeared within top 10 words in current decade (2011-2018); [Table/Fig 9: C1 and C2]. It has also been observed that frequency of occurrence of the words "vertical", 'ground', 'reaction' and 'force' were almost closer and ranked within top 10 words used in current decade [Table/Fig-10]. These observations indicated that VGRF appeared in recent decades most frequently in research articles reporting manual lifting. Past researches on the topic, as presented in literature review using meta-analysis, also supported the fact that VGRF was a very important determinant for assessing physically strenuous tasks [16,19,36, 49,52]. The salient findings of the study can be extrapolated for understanding the injury risk potential of MLT carried out by similar population elsewhere, both within and outside the country.

Word frequency (Rank)			
Keywords	Year (1991-2000)	Year (2001-2010)	Year (2011-2018)
Vertical	5 (6)	16 (10)	34 (9)
Ground	3 (21)	16 (7)	42 (5)
Reaction	2 (60)	13 (16)	34 (10)
Force	13 (1)	27 (4)	55 (4)

[Table/Fig-10]: Frequency and ranking of words vertical, ground, reaction and force from literature in the context of manual lifting tasks by applying meta-analysis techniques.

Limitation(s)

The limitation of the present study is that the meta-analysis literature survey was conducted only on abstracts from PubMed. As number of articles pertaining to MLT in last three decades were huge and extensive meta-analysis pertaining to full length articles was beyond the scope of the current review, only abstracts were considered. Salient findings of the review can be effectively extrapolated for understanding the injury risk potential of MLT carried out by similar population elsewhere, both within and outside the country.

CONCLUSION(S)

The datasets of 12 independent variables (varying conditions of lifting weight, height and frequency) and 26 dependent parameters of MLT were analysed by multivariate statistical analysis technique using principle component analysis and clustering. The analysis singled out 'lifting height' and VGRF as most significant independent and dependent determinants of MLT, respectively. The meta-analysis approach validated the statistical analysis results. Thus, it may be suggested that 'lifting height' and VGRF could be important determinants to assess manual load lifting related tasks. However, for establishing lifting height and VGRF as the indicator for assessing injury risk potential of MLT on different population, 'holistic ergonomics' assessment on larger sample size and meta-analysis of relevant full papers instead of abstracts needs to be done in future.

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