Correlation between Different Hand Force Assessment Methods from an Epidemiological Study

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Abstract

This article presents the outcome of correlation analyses of data results obtained from using different methods for objectively and subjectively assessing hand force from a prospective study of 450 blue-collar workers from several companies and industries, followed for up to 3 years. The study collected detailed ergonomic exposure data at baseline and upper extremity health outcome data at baseline and every 4 months during the study. Ultimately, the study was intended to evaluate dose-response relationships of specific upper extremity disorders with detailed physical and psychosocial exposure data at the workplace while controlling for important individual factors. This article presents the methods used to collect data, as well as the hand force results of the epidemiological study in aggregate correlated form, as a means of exploring the degree of independence between the variables considered. These insights are useful in identifying musculoskeletal disorder (MSD) causation and predicting MSD risk based on work exposures. An enhanced understanding of the independence of MSD causal factors is instrumental in establishing more accurate multivariable models of MSD causation that will play an important role in extrapolating from the understanding of mechanisms of causation to establishing effective recommendations and programs to prevent the occurrence of MSDs.

Keywords: Musculoskeletal disorders (MSDs); Grip and pinch forces; Exposure assessment; Multivariable models of MSD causation

1. INTRODUCTION

Musculoskeletal disorders (MSDs) are prevalent, potentially disabling conditions (Lawrence et al., 1998) with enormous social costs (Badley, Rasooly, & Webster, 1994; Felts & Yelin, 1989). In industrialized societies, they are the main cause of permanent work disability and functional loss in adults (Meerding, Bonneux, Polder, Koopmanschap, & van der Maas, 1998; Reynolds et al., 1992; Van Schaardenburg, van den Brade, Ligthart, Breedveld, & Hazes, 1994; Yelin, Henke, & Epstein, 1986) and the second leading cause of short-term temporary work disability (Badley, 1995), with productivity losses of up to 1.3% of U.S. gross national product (Yelin & Felts, 1990). Total costs accruing from MSDs include direct health care costs and indirect costs from a variety of factors, such as loss of productivity (Leon et al., 2009). Indirect costs can be two to twenty

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times the losses from direct costs, depending on the industry.

Repetition, forceful hand actions, abnormal hand postures, vibrations, and deprivation of rest have all been previously identified as risk factors for the development of MSDs (Babski-Reeves & Crumpton-Young. 2002; Stock, 1991). In particular, repetitive hand activity has been linked to the development of several upper-extremity MSDs, including carpal tunnel syndrome (CTS) (Birkbeck & Beer, 1975; Silverstein, Fine, & Armstrong, 1987), tendonitis (Silverstein, Fine, & Armstrong, 1986), and epicondylitis (Feldman, Goldman, & Keyserling, 1983). It is believed that many of these musculoskeletal diseases are contracted as a result of work-related activity. Accordingly, these diseases are often referred to as "occupational diseases" (Birkbeck & Beer, 1975). Occupational musculoskeletal diseases are prevalent in the American workforce. In fact, in 2006, 30% of all work injuries in the United States that required a leave of absence were attributed to occupational MSDs (U.S. Department of Labor, Bureau of Labor Statistics, 2006). Blue-collar workers are especially at risk for the development of MSDs because their work often requires them to perform prolonged repetitive tasks (Atroshi et al., 1999). If the correlation between forceful work and the increased incidence of MSDs among blue-collar workers could be characterized, preventative changes to the workplace could be determined, widely disseminated, and put into place. Providing a contribution to the realization of this overarching aim, the goal of this article is to investigate the independence between subjective and objective hand force variables assessed in epidemiological study. Understanding the degree of proportionality among variables could benefit the process of establishing multiple-variable models of causation and assessment of the risk of MSDs based on work exposures. The greater the confounding effects determined among causal factors of MSDs, the simpler the models that might be built. Simple but accurate models of MSD causation may be used more widely and become more rapidly adopted than more complex ones.

The current section contextualizes the analysis presented within the encompassing epidemiological study, providing information on the study base, health outcome measures, and exposure assessment methods. The following sections focus on the methods of analysis for this article, the results from the correlation analyses, and a discussion of the expected and observed independence between variables.

1.1. Epidemiological Study of Musculoskeletal Symptoms and MSDs

There is a substantial body of epidemiologic data linking various workplace risk factors and the development of upper extremity MSDs. Unfortunately, due to small sample sizes, cross-sectional designs, lack of uniform diagnostic criteria, and crude exposure assessment methods, the dose-response relationships for specific disorders are not well characterized. The San Francisco, California, study (currently in publication of results phase) is one of six prospective studies in the United States of musculoskeletal symptoms and MSDs among blue-collar workers.

This prospective study collected detailed information on upper extremity musculoskeletal health and ergonomic exposures to determine dose-response relationships between workplace physical exposures and incident cases of specific upper extremity disorders. The long-term objective of this research is to provide employers, employees, and public agencies with quantitative risk relationships that can guide health and safety policy.

Four hundred fifty blue-collar workers were followed for up to 28 months with detailed individual exposure assessment and physical examinations. Outcome health measures were assessed at baseline and every 4 months thereafter. The study was approved by the university committee on human research.

Industries involved in manufacturing or production with a large percentage of jobs involving hand intensive, non-office work were recruited from geographically different locations in the United States, including California, Nevada, and Illinois. The participating companies produced artificial stone, furniture, dairy foods, and mushrooms.

Full-time employees having four or fewer tasks were recruited. Exclusion criteria included employees who had worked for their current employer less than three months, those who did not expect to be working for their current employer for at least one year, and those who spent more than 25% of their time on a forklift or a computer.

1.2. Health Outcome Measures

The health outcome measures included health and work questionnaires, distal median and ulnar nerve conduction tests, and physical examination of the upper extremities.

Baseline data collection included assessment of medical history, non-work factors, psychosocial data, a nerve conduction test of the median and ulnar nerves at the wrist, and a standardized physical examination, if triggered. The physical examination was triggered at 4-month intervals for the neck/shoulder, forearm, or hand/wrist region when the following criteria were met: pain in the region occurred in the last four months and was thought to be work related, and was associated with a pain rating of 5 or greater on a 10-point scale in the past seven days or was treated with pain medication for at least 2 of the past 7 days. Physical examination maneuvers were performed by a trained physical therapist who was blinded to exposure status. The examination was standardized, and diagnostic criteria were developed a priori for specific upper extremity disorders using a combination of symptoms and physical examination findings (e.g., deQuervain's disease, ulnar neuropathy at elbow, lateral epicondylitis). For example, the CTS case definition was: 1) the presence of numbness, tingling, burning, or pain in one or more of the first three digits (thumb, index finger, or long finger); and 2) abnormal Electrodiagnostic Study (EDS) consistent with CTS. A prevalent case at baseline could not become an incident case.

1.3. Ergonomic Exposure Assessment

Job title, tasks, and time allocated to each task (hours per day) were assessed for all subjects at baseline. The full exposure assessment protocol included subject interviews and observation by a trained technician who was blinded to health outcomes. In addition, each task was video recorded for at least 10 minutes. Subjects in the study performed a number of tasks of which up to six different tasks were registered in the study. Data were collected for up to four tasks per subject. Jobs with rotation and jobs with more than 25% of work time assigned to clerical functions were excluded. The exposure evaluation was repeated if the subject changed jobs or tasks.

The exposure data included sufficient information to calculate bilateral ACGIH (American Conference of Governmental Industrial Hygienists) hand activity level (Latko et al., 1999) and strain index (Moore & Garg, 1995). Some of the variables were duty cycle, rate of hand exertions, duration of tasks, speed of work, posture, and effort. These variables were assessed by a trained technician or from the videotape analysis. Subjects rated perceived exertion for each task for peak hand force using the Borg CR10 Scale (Borg, 1982). Tool handling information, posture, contact stress, glove use, peak pinch and grip force, and peak activity and nongrip force were measured for each task. An average of three trials of force matching measurements and maximum voluntary contractions (Bao, Spielholz, Howard, & Silverstein, 2006) in the task position was assessed to calculate percentage of maximum voluntary contraction required for each task. These trials resulted in the collection of data for the variables of peak grip force, peak hand (nongrip) force, and peak force activity measurements (force matching).

Video analysis of each task using Multimedia Video Task Analysis (MVTA) software (Yen & Radwin, 1995) was performed to classify on a frame-by-frame basis hand postures and force: no load, light pinch (< l kg), significant pinch (>1 kg), light grip (<4 kg), and significant grip (>4 kg) (Bao et al., 2006). The frequency of hand or wrist exertions was also calculated. Video classification of mutually exclusive grip was used to calculate percentage of time and frequency of hand postures, loads, and repetition rates (hand exertions per minute). Other workplace factors evaluated were psychosocial factors, wrist posture, contact stress, and vibration.

1.4. Summary of Data Collection Outcome

Among 643 eligible individuals, 450 workers participated in the study and 183 declined participation (70% participation rate). At baseline, 213 (47%) reported persistent hand and/or wrist pain in the past 12 months. Of these, 48 (23%) reported difficulty with work pace or quality, and 13 (6%) reported changing jobs due to the hand and/or wrist pain. The number of subjects with at least 4 months of follow-up data was 413.

The prevalence rate for epicondylitis (medial or lateral) was 5.0 cases per 100, and the incidence rate was 2.1 cases per 100 person-years. The prevalence rate of wrist tendonitis on the flexor side was 3.2 per 100 and on the extensor side was 10.4 per 100. The incidence rates were 3.7 and 7.4 per 100 person-years, respectively.

The number of subjects at baseline with a nerve conduction study was 434. The prevalence of CTS at baseline, based on probable symptoms and nerve conduction, was 9.4 cases per 100. The incidence rate was 10.5 cases per 100 person-years.

The preliminary findings from this prospective study of blue-collar workers showed that pain in the hand and wrist region was common and had an important impact on work function. The study can characterize the prevalence and incidence of specific hand and/or wrist disorders based on standardized symptoms and physical examination criteria. Ultimately, by combining data from the six study sites, the investigation will have the power to evaluate the dose-response relationships between specific biomechanical risk factors and incident distal upper extremity disorders.

1.5. Intent of the Correlation Analyses

This article is intended to present the results of investigating the degree of interdependence of the variables collected in the epidemiological study, by means of assessing their aggregate correlated dependencies. This understanding will contribute to the distinguishing between confounded effects among causal variables, in the process of building multiple-variable models of causation and assessment of the risk of MSDs based on work exposures. An enhanced understanding of independence of MSD causal factors will enable the establishment of more accurate multivariable models of MSD causation. These will be expected to play an important role in extrapolating from the understanding of mechanisms of causation to establishing effective recommendations and programs to prevent the occurrence of MSDs.

2. DESCRIPTION OF VARIABLES

This section presents the variables that are correlated in this article and provides information on the experimental setup and data analysis procedures pertaining to the epidemiological study. It also provides an overview of the data, collected in the epidemiological study, that was correlated pair-wise in this study (Table 1).

2.1. Experimental Setup

In the epidemiological study, various subjective and objective exposure data were collected. Measurements were made of peak grip force (PGF), peak hand (non-grip) force (PHF) and peak force activity (matching) measurement (PFAM). Object and/or tool weight (OTW) were estimated. Three primary methods of estimating exertion were used and are explained in more detail in the following subsections: 1) quantifying the precise number of exertions per minute using MVTA video analysis software, 2) assigning qualitative HAL (Hand Activity Level; Latko et al., 1999) ratings, and 3) using the blue-collar subjects' self-reported "fatigue" ratings. HAL ratings were made both at baseline (HAL-b) and for task- and hand-specific activity (HAL). Similarly, rate of perceived exertion (RPE – Borg CR10 Scale; Borg, 1982) was assessed at baseline (RPE-b) and for task-specific activity (RPE). In both cases the assessment was made by the worker.

2.1.1. Determination of Exertions per Minute Using MVTA

Blue-collar subjects were video recorded as they performed up to four different tasks that were representative of their daily work activities. Because one subject may have had several different tasks, repetition was calculated on a per task basis. A minimum of 10 minutes of video footage was analyzed for each subject using the MVTA software, which allows the user to define the durations of a given subject's tasks by making a break point at the start of each new task. Additionally, frames were marked to indicate the type of mutually exclusive hand activity to quantify the percentage of time spent in each hand activity by task. The subject's left and right hands were analyzed separately, and the possible hand activities of each hand were broken down into six categories: 1) No Data: the subject's hand cannot be seen in the video; 2) No Load: the subject's hand is not holding anything or exerting any force; 3) Light Pinch Grip: the subject's hand is in a pinch grip and is exerting less than 1 kg of force; 4) Significant Pinch Grip: the subject's hand is in a pinch grip and is exerting more than 1 kg of force; 5) Light Power Grip: the subject's hand is in a power grip and is exerting less than 4 kg of force; and 6) Significant Power Grip: the subject's hand is in a power grip and is exerting more than 4 kg of force.

MVTA video analyses were conducted for more than 200 subjects. It was determined that the total number of exertions for a given subject during a given task could be approximated by the total number of times a subject's hand activity was marked during that task. To ensure that every hand exertion was recorded, the diary site videos were reviewed an additional time. A separate break point was marked for each individual hand

TABLE 1. Identification and Description of the Variables Correlated in the Present Study

Variable	Description
HAL – Hand Activity Level (exposure assessment questionnaire, task and hand specific, observer rating)	Observer-based allocation of hand activity level for each task
OTW – Object or Tool Weight (exposure assessment questionnaire, task and hand specific, observer assessment)	Direct measurement using scale or force gauge of any tools >2 lb held/used during primary tasks
PHF – Peak Hand Force (exposure assessment questionnaire, task and hand specific, measured)	Overall highest value of measured hand force created by the hand regardless of grip, pinch, or no grip at all
PGF – Peak Grip force (exposure assessment questionnaire, task and hand specific, measured)	The average of 3 trials for maximum voluntary contraction in the position of use and the average of 3 trials for the gripping activity
PFAM – Peak Force Activity Measurement (matching of measured force with perceived force exertion in activity (exposure assessment questionnaire, task and hand specific, worker rated)	The average of 3 trials of nongrip activities, such as pushing, pulling, lifting/lowering, turning, and the average of 3 trials matching the activity assessed
RPE – Rate of Perceived Exertion (exposure assessment questionnaire, task specific, non-hand specific, worker rated)	Observer based or subjective rating of the perceived exertion of each task
VAS - Subjective "fatigue" from VAS (Visual Analogue Scale, exposure assessment questionnaire, task and hand specific, worker rated)	A worker-rated mark indicating the fatigue of each hand on a 10 cm line for each task
SPG&SP – Significant Power Grip and Significant Pinch (exertions per minute using MVTA, task and hand specific)	Duration of a task in significant pinch (>1 kg) or power grip (>4 kg) by side
AllG&P – All exertions, including light and significant Power Grip and Pinch (exertions per minute using MVTA, task and hand specific)	Duration of a task in any pinch or power grip by side
AnyP – Any Pinch, both Light Pinch and Significant Pinch (exertions per minute using MVTA, task and hand specific)	Duration of a task in any pinch posture by side
OnlySP – Only Significant Pinch (exertions per minute using MVTA, task and hand specific)	Duration of a task in significant pinch (>1 kg) by side
HAL-b – Hand Activity Level (baseline assessment questionnaire, encompassing all tasks, hand specific, worker rated)	Worker-estimated rating of all tasks
RPE-b – Rate of Perceived Exertion (baseline assessment questionnaire, encompassing of all tasks, non-hand specific, worker rated)	Worker-estimated rating of all tasks

exertion, even if the subject did not change hand grips. After all of the repetition video analysis was complete, a Microsoft Excel 2007 macro was designed to automatically process the data. The macro totaled the number of break points for all hand activities (excluding no data and no load) for a given task and divided this value by the total time for each task to determine the number of exertions per minute per task for a given subject. After the data were available, they were further processed for the purpose of the correlation, creating four categories (SPG&SP, AllG&P, AnyP, OnlySP) depicted in Table 1.

2.1.2. Determination of HAL Measurements

The HAL rating is meant to be a qualitative assessment of hand repetition. HAL ratings were recorded at baseline and for each hand for each task of a given subject. To determine these HAL ratings, a trained ergonomist went on-site to observe the subject's typical work conditions. The ergonomist's visual observations of the subject were compared to a standard HAL rating scale (originally developed by ACGIH) to determine the specific HAL ratings (Bernard & ACGIH, 2002). Each HAL rating was recorded on a field exposure survey on-site and later digitized in a Microsoft Excel spreadsheet. HAL ratings were also self-reported at baseline (HAL-b) by the subjects (these ratings were not task specific, but considered the overall job conditions).

2.1.3. Determination of Self-Reported Subjective "Fatigue" Measurements

The self-reported subjective fatigue measurement allows a subject to communicate his or her personal perception of fatigue in each hand after performing a given task. A visual analog scale (VAS) was used to determine these self-reports of fatigue. Subjects were shown the VAS, which ranges from No fatigue (0) to Extreme fatigue (10), and were asked to mark the position on the scale that they felt best corresponded to the fatigue that they experienced after performing a given task for each hand. After all of the VAS marks were collected for all of the subjects in the study, each mark was given a quantitative value by calculating the length of the line segment that spans from 0 to the mark made by the subject. These lengths (which range from 0 cm, No fatigue, to 10 cm, Extreme fatigue) were used as the subject's subjective fatigue measurement. Each measurement was recorded on a field exposure survey on-site and later digitized in a Microsoft Excel spreadsheet.

2.1.4. Determination of RPE Measurements

A category ratio scale with values from 0 to 10 and verbal anchors (Borg's CR10 Scale; Borg, 1982) was used as the basis for the measurement of RPE, which was assessed by the worker at baseline (RPE-b), considering the overall job carried out, and for task specific activity (RPE). In both cases the assessment was made by the worker. Exceptionally, if the worker was unable or unwilling to subjectively rate perceived exertion, the trained observer could provide an assessment. Each RPE rating was recorded on a field exposure survey on-site and later digitized in a Microsoft Excel spreadsheet.

3. RESULTS

In this section, the procedures involved in implementing the correlation analyses performed are presented, as well as the results of the correlation analyses. The fundamental results of this study are these correlation analyses carried out for the pairings of the variables expressed in Table 1. In general, data are scattered throughout the subject pool of the epidemiological study. Individual subject counts of existing data for each variable are generally low compared to the total number of participating subjects. To establish the pairings, task-specific data were first organized into four tasks for each individual subject. These four tasks were ordered by ascending task code number within each set of individual and task-specific data. Simple correlations were computed for the pairings found, using both the Pearson determinant of correlation (calculated in a Microsoft Excel spreadsheet) and the Spearman rank-order correlation coefficient (calculated from free statistics software developed by Wessa, 2010).

The pairings were extracted from matching data for variable pairings for task 1, and then seeking matches for subjects that were not represented in task 1, within task 2. The same process was followed for tasks 3 and 4. The aforementioned process of polling subtask data yielded a random sampling of individual task data. Tasks were ordered in ascending order by task code (e.g., for each individual subject, the task with the lowest task code was given the designation of task 1, the task with the next greater task code was given the designation of task 2, and so on). Hence, each subject is represented only once (if data are available) in each set of data pairs, and one (if any) task carried out by an individual subject is represented in each particular pairing of variables. Note however that this process of pairing data results in discarding unpaired data for subjects, given the scattered nature of the original data, which can be appreciated by analyzing the reduction from individual data counts to paired data counts.

3.1. Results of Correlation Analyses

Correlation analyses were performed for all possible pairings of the variables listed in Table 1. Pearson determinants of correlation (R^2) are presented in Tables 2 (left hand data) and 3 (right hand data). These correlation analyses are based on pairs of variables pertaining exclusively to continuous, interval data. Interval data concerns variables OTW, force variables (PHF, PGF, and PFAM), VAS, and video-based data (SPG&SP, AllG&P, AnyP, and OnlySP). The results of correlations pertaining to pairs involving at least one discontinuous variable are shown in Tables 4 (left hand data) and 5 (right hand data). Discontinuous variables concern

TABLE 2. Determinant of Correlation (Pearson's R^2) of Data Pairs for the Interval Variables Described in TABLE 1 – Left Hand

Pearson's R^2	OTW	PHF	PGF	PFAM	VAS	SPG&SP	AllG&P	AnyP	OnlySP
OTW	1 (53)	0.340 (32)	0.481 (31)	0.737 (3)	0.293 (22)	0.036 (24)	0.000 (24)	0.008 (24)	0.050 (24)
PHF		1 (57)	**0.741** (34)	0.978 (6)	0.204 (34)	0.011 (33)	0.004 (33)	0.010 (33)	0.016 (33)
PGF			1 (167)	0.992 (4)	0.010 (106)	0.026 (49)	0.025 (49)	0.075 (49)	0.000 (49)
PFAM				1 (8)	0.033 (5)	0.062 (5)	0.285 (5)	0.613 (5)	0.336 (5)
VAS					1 (199)	0.001 (67)	0.001 (67)	0.018 (67)	0.006 (67)
SPG&SP						1 (121)	0.164 (121)	0.262 (121)	0.751 (121)
AllG&P							1 (121)	0.213 (121)	0.132 (121)
AnyP								1 (121)	0.447 (121)
OnlySP									1 (121)

Note: Numbers in parentheses indicate the total pairs available, and the existing data count in the diagonal.

the results expressed in ordinal data (Hal, RPE, HAL-b, and RPE-b). For the correlations involving at least one of these variables, the Spearman rank-order correlation coefficient was calculated, because it is applicable to nonparametric data.

The highest determinants of correlation (not related to variable PFAM) depicted in Tables 2 and 3 concern the matching of the individual subject data for the variables PHF and PGF, for both left and right hand. Correlations involving variable PFAM are especially high. However, due to low numbers of existing data (only eight data points for the left hand and nine data points for the right hand), these high values of correlation determinants (Pearson) and rank-order correlation coefficient (Spearman) are inconclusive, given the low matching size. The pairing of variables VAS (subjective fatigue reported on a visual analogue scale) and RPE (rate of perceived exertion) yielded the highest correlation coefficient considering the universe of data pairs subjected to Spearman's correlation calculations, shown in Tables 4 and 5.

Additional studies of correlation (considering the Pearson determinant of correlation) for a smaller number of variables were performed using as criteria for selection of data the task of longest duration instead of a randomly selected task for each subject as presented in Tables 2 through 5. These results are shown in Tables 6 and 7. This additional set of correlations was established to test whether selection of individual data for correlation within each available pair influenced correlation results according to task duration or randomly.

TABLE 3. Determinant of Correlation (Pearson's R^2) of Data Pairs for the Interval Variables Described in TABLE 1 – Right Hand

Pearson's R^2	OTW	PHF	PGF	PFAM	VAS	SPG&SP	AllG&P	AnyP	OnlySP
OTW	1 (104)	0.125 (69)	0.182 (76)	0.864 (4)	0.094 (57)	0.029 (58)	0.052 (58)	0.015 (58)	0.045 (58)
PHF		1 (92)	**0.859** (73)	0.318 (9)	0.069 (59)	0.015 (62)	0.008 (62)	0.119 (62)	0.012 (62)
PGF			1 (164)	0.335 (5)	0.006 (97)	0.002 (89)	0.016 (89)	0.052 (89)	0.036 (89)
PFAM				1 (9)	0.312 (6)	0.124 (6)	0.101 (6)	0.016 (6)	0.059 (6)
VAS					1 (200)	0.008 (93)	0.004 (93)	0.002 (93)	0.038 (93)
SPG&SP						1 (192)	0.135 (192)	0.058 (192)	0.699 (192)
AllG&P							1 (192)	0.209 (192)	0.103 (192)
AnyP								1 (192)	0.318 (192)
OnlySP									1 (192)

Note: Numbers in parentheses indicate the total pairs available, and the existing data count in the diagonal.

TABLE 4. Spearman's Rank Order Correlation Coefficient (r.o.c.c.) Calculated for Data Pairs for the Interval of Variables Described in TABLE 1, Where at Least One of the Variables Was Discontinuous – Left Hand

Spearman's r.o.c.c.	HAL	RPE	HAL-b	RPE-b
HAL	1 (194)			
RPE	0.2 (130)	1 (202)		
HAL-b	0.108 (192)	0.103 (199)	1 (444)	
RPE-b	0.066 (191)	0.202 (199)	0.310 (437)	1 (443)
OTW	−0.38 (23)	−0.27 (22)	−0.15 (52)	0.013 (52)
PHF	0.135 (26)	−0.07 (34)	−0.04 (55)	0.386 (55)
PGF	0.557 (109)	0.174 (111)	−0.03 (164)	0.225 (165)
PFAM	0.875 (3)	0.300 (5)	0.732 (8)	0.786 (8)
VAS	0.035 (126)	**0.681 (187)**	0.124 (196)	0.115 (196)
SPG&SP	0.085 (46)	−0.030 (65)	0.026 (119)	0.152 (120)
AllG&P	0.044 (46)	0.022 (65)	−0.12 (119)	−0.03 (120)
AnyP	−0.09 (46)	0.016 (65)	−0.02 (119)	0.002 (120)
OnlySP	0.025 (46)	−0.04 (65)	0.054 (119)	0.092 (120)

Note: Numbers in parentheses indicate the total pairs available.

TABLE 5. Spearman's Rank Order Correlation Coefficient (r.o.c.c.) Calculated for Data Pairs for the Interval of Variables Described in TABLE 1 ,Where at Least One of the Variables Was Discontinuous – Right Hand

Spearman's r.o.c.c.	HAL	RPE	HAL-b	RPE-b
HAL	1 (194)			
RPE	0.189 (130)	1 (202)		
HAL-b	0.061 (192)	0.103 (199)	1 (444)	
RPE-b	0.048 (191)	0.202 (199)	0.310 (437)	1 (443)
OTW	0.344 (48)	0.031 (58)	0.044 (102)	0.021 (103)
PHF	0.042 (41)	−0.27 (57)	−0.02 (90)	0.406 (90)
PGF	0.309 (103)	0.083 (99)	−0.02 (163)	0.326 (161)
PFAM	0.843 (6)	0.286 (6)	0.479 (9)	0.661 (8)
VAS	−0.04 (126)	**0.683** (188)	0.09 (197)	0.128 (197)
SPG&SP	0.068 (64)	0.329 (88)	0.17 (188)	0.199 (188)
AllG&P	0.162 (64)	0.092 (88)	0.054 (188)	0.116 (188)
AnyP	−0.12 (64)	0.055 (88)	0.116 (188)	0.017 (188)
OnlySP	0.026 (64)	0.381 (88)	0.231 (188)	0.129 (188)

Note: Numbers in parentheses indicate the total pairs available.

A comparative analysis of Tables 2 and 6 shows that the latter depicts correlation values in the same order of magnitude as their counterparts in Table 2, with some minor variations both upward and downward. Likewise, comparing reciprocal values in Tables 3 and 7 yields the same general impression. In particular, 11 of the 21 pairs of variables correlated and that are comparable between Tables 2 and 6 changed in the direction of increase, whereas the 10 remaining ones decreased. The same impression results from comparing Tables 7 and 3, with 10 increases in correlation (from Table 3 to Table 7) and 11 decreasing correlation coefficients.

Given the outcome of comparing two alternative criteria for selection of individual data for correlation within each available pair, exchanging randomness for task duration has a minor impact on the correlation coefficients seen overall. Moreover, sample size changes, whether upward or downward, do not predict the direction of change in the respective correlation coefficients (some of these decrease whereas others increase, irrespective of the increase or decrease in sample size).

TABLE 6. Determinant of Correlation (Pearson's R^2) of Selected Data Pairs for the Interval Variables Described in TABLE 1 – Left Hand, Considering the Task of Greatest Duration

Pearson's R^2	OTW	PGF	VAS	SPG&SP	AllG&P	AnyP	OnlySP
OTW	1 (37)	0.558 (25)	0.347 (18)	0.033 (17)	0.003 (17)	0.189 (17)	0.181 (17)
PGF		1 (45)	0.104 (23)	0.031 (27)	0.001 (27)	0.010 (27)	0.089 (27)
VAS			1 (164)	0.049 (56)	0.062 (56)	0.105 (56)	0.066 (56)
SPG&SP				1 (134)	0.249 (134)	0.011 (134)	0.299 (134)
AllG&P					1 (134)	0.062 (134)	0.064 (134)
AnyP						1 (134)	0.400 (134)
OnlySP							1 (134)

Note: Numbers in parentheses indicate the total pairs available and the existing data count in the diagonal.

TABLE 7. Determinant of Correlation (Pearson's R^2) of Selected Data Pairs for the Interval Variables Described in TABLE 1 – Right Hand, Considering the Task of Greatest Duration

Pearson's R^2	OTW	PGF	VAS	SPG&SP	AllG&P	AnyP	OnlySP
OTW	1 (78)	0.125 (54)	0.107 (50)	0.007 (33)	0.172 (33)	0.020 (33)	0.028 (33)
PGF		1 (78)	0.032 (47)	0.003 (42)	0.000 (42)	0.175 (42)	0.085 (42)
VAS			1 (164)	0.019 (56)	0.014 (56)	0.025 (56)	0.035 (56)
SPG&SP				1 (134)	0.146 (134)	0.013 (134)	0.309 (134)
AllG&P					1 (134)	0.113 (134)	0.021 (134)
AnyP						1 (134)	0.250 (134)
OnlySP							1 (134)

Note: Numbers in parentheses indicate the total pairs available and the existing data count in the diagonal.

A general diminishing in sample size is observed when proceeding from Table 2 to Table 6 and from Table 3 to Table 7. This is deemed to occur because the task of greatest duration for each individual subject was not necessarily the one where data collection had been more intensive. In the epidemiological study, there was a level of random variability inherent to the duration of the task the subjects were carrying out when specific data were collected.

4. DISCUSSION

This section discusses the results, especially in what concerns their compliance with the expected level of independence between variables under focus. The discussion attempts to shed light on the implications of the results obtained from the correlation analyses established for the different methods for assessing and quantifying hand force and exertion. A general appreciation of the results suggests that, correlation wise, consistency between left and right hand is good. Seldom were high values of correlation found. High correlation was identified between only two variable pairs (PHF – PGF and VAS – RPE), suggesting interchangeability within each pair in a multivariable model of MSD causality.

4.1. Comparisons Involving Different Force Measurement Approaches

Three methods were used to quantify hand force, but only two of these yielded large samples of measurements. A strong correlation was found between these two variables, suggesting that their degree of independence is low. The determinant of correlation computed using Pearson's R^2 is higher for the right hand, which also has more than twice the data than the left hand. These results suggest that both variables are interchangeable to a great extent in a multivariable model of the causality of MSDs. In what concerns the pairings of force variables with other variables, HAL data are moderately correlated with PGF for the left hand, more so than for the right hand.

A variable that does not quantify force, but is directly linked to force, OTW, was found not to be correlated to any of the other variables considered, concerning right hand data. In terms of left hand data, the highest correlation was calculated in pairing with PGF, reaching 48% determination. This finding suggests that, for most right-handed subjects, left-hand load increases with object and tool weight increase. The negative correlation coefficient between OTW and HAL for the left hand suggests that repetition frequency (associated with HAL) decreases with increased static load (OTW).

4.2. Comparisons Between Exertion Data

Exertion data concern subjective ratings, including the variables VAS, HAL, HAL-b, RPE, RPE-b, and the variables resulting from the MVTA analysis (SPG&SP, AllG&P, AnyP, and OnlySP). Except for the pairs HAL-PGF (left hand) and HAL-OTW, previously discussed, comparisons across domains of variables did not yield moderate or high values of correlation. The comparisons among exertion variables are discussed in the following subsections.

4.2.1. Comparison Between Task Specific and General Exertion Assessments

Two of the exertion variables used for data matching were collected at baseline of the epidemiological study for both overall job of the subject (HAL-b and RPE-b) and according to task performed (HAL and RPE). The remaining variables are task specific. In both cases (comparing HAL with HAL-b and comparing RPE with RPE-b) the correlation coefficients are low.

Subjective fatigue, measured with VAS, is consistently correlated with RPE but not with RPE-b, for both hands. This finding suggests that, within the same task, these two variables (VAS and RPE) are highly dependent (with correlation coefficients of 0.68).

4.2.2. Comparison Between Rated Exertion and Exertion from Video Analysis

Comparisons between MVTA variables and VAS show a low correlation determinant, nearing null, in all pairs, for both hands. This finding suggests total independence between these variable pairs. When MVTA variables are correlated with discontinuous subjective exertion variables, similar results can be found, with the exception of some of the right-hand pairings involving the RPE variable. In this case, low correlation coefficients are found for the pairs SPG&SP-RPE and OnlySP-RPE, suggesting that, for the right hand, approximately one third of the RPE rating can be explained by long duration of significant exertion (especially significant pinch) of the right hand. The results, however, do not support suggesting the same effect for the left hand. Therefore, these variables should be considered independent in multivariable models of MSD causation.

5. CONCLUSION

When the data sets obtained from a prospective study of 450 blue-collar workers aimed at investigating the causality of MSDs are matched in pairs subject by subject, resulting data counts diminish significantly from the overall sample size. For most variables, the resulting pairings have sample sizes that enable correlation analyses, focusing on hand side–specific data, for most variables. The results of the correlation analyses demonstrate that most of the variables considered are independent from each other and that they measure different characteristics of hand activity. There were some exceptions, specifically RPE-VAS and PGF-PHF, where high determinants of correlation, and/or correlation coefficients were obtained. The multivariate models of causation of MSDs should consider the covariance between these variables and not include both in the same models.

Two alternative methods of pairing up data for correlation were trialed, using as criteria for data selection (for each subject in every data pair considered) the task with greatest duration, as an alternative to randomly selecting one task per subject. The results show values of correlation with similar order of magnitude, and suggest that both subject data pairing selection criteria, whether random or according to task of greatest duration, lead to similar results.

From the analyses of correlation performed, it is possible to suggest the existence of a difference in subjective perception of exertion and repetition concerning the right and left hand. The proportion of self-reportedly left-handed workers in the epidemiological study was 2.83%.

In this epidemiological study, "subjective reported fatigue" measured in VAS was collected separately for right and left hands and for each task (up to four tasks per subject). The high correlation attained for the pairing RPE-VAS and the comparison of left- and right-hand histograms of the latter variable suggests, however, that the rankings were fairly the same for both hands. This result could have been caused by a cognitive issue, resulting in the dominance of the right hand, meaning that, for most subjects (right-handed), the left hand is less "consciously" remembered or felt. The exertion unbalance tends toward the right hand, as seen from histograms, especially for some of the video data.

This article investigated the degree of interdependency between the variables collected in an epidemiological study about MSD causality, by means of assessing their aggregate correlated dependencies. Few variables were found to be strongly correlated among each other, suggesting that multiple-variable models of causation and assessment of the risk of MSDs based on work exposures may be difficult to reach, and certainly, if attainable, will have to involve a large number of causal factors to enable establishing accurate models of MSD causation.

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