Journal of Occupational Rehabilitation, Vol. 14, No. 4, December 2004 (© 2004)

# Observational Assessment of Forceful Exertion and the Perceived Force Demands of Daily Activities

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*The primary objective of this study was to assess the accuracy and precision with which analysts observe and estimate the force produced as subjects performed exertions on a work simulator. Eight analysts observed 32 subjects and estimated force as a percent of subjects' maximum voluntary contraction (% MVC). Analysts exhibited bias toward the mean, as high force exertions (>67% MVC) were underestimated (mean: 11.6% MVC) and low force exertions (<34% MVC) were overestimated (mean: 6.7% MVC). Average error for medium force exertions (34–67% MVC) was not statistically different from zero (2.1% MVC). For all force levels, precision of the estimate was very poor (standard deviation range: 16.2–20.7% MVC). Experience of the analyst in performing ergonomic analysis did not affect accuracy. A secondary objective of the study was to conduct a survey in which subjects identified activities of daily living they perceived as equivalent to controlled force levels. A total of 59 different activities ranging from minimal force required to near maximum were listed by at least 5% of the participants. This list may be used to assist health care practitioners and patients convey the force demands required of occupational tasks as well as for evaluating the diminished strength of the patient.*

**KEY WORDS:** observational assessment; ergonomic risk factors; forceful exertion.

## INTRODUCTION

The detrimental effects of work-related musculoskeletal disorders (WRMSD) on work-force participation are well-documented. One obstacle that researchers, ergonomists, and health care providers all face in evaluating WRMSDs is a lack of validated and efficient tools with which to quantify the ergonomic risk factors attributed to these disorders. In rehabilitation settings this presents a challenge for health care providers who need to determine what the physical demands are of the work that an injured worker performs so that appropriate recommendations may be made regarding workplace accommodations and rehabilitation. One method employed is observational assessment, in which an outside observer watches

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1053-0487/04/1200-0281/0 © 2004 Springer Science+Business Media, Inc.

a worker perform the job. The observer(s) then assign a numeric value to the exposure proportional to its perceived magnitude. Observational methods offer an advantage in that they do not interfere with the task, thereby minimizing disruption.

Several observational techniques have been proposed to assess exposure to ergonomic risk factors (1). Among the more established methods for evaluating extreme and awkward posture are the Ovako Working Posture Analyzing System (OWAS) (2,3) and the Rapid Upper Limb Assessment (RULA) (4,5). Li and Buckle (6) provide a comprehensive review on the use of observational techniques for the assessment of posture. Similar to posture, in which the position of the joints is observed, hand activity level, or repetition, may be assessed by observing the activity of the worker's hands as the task is performed. Latko *et al.* (7,8) developed and validated an observational rating scale for hand activity level that uses clearly defined verbal descriptions and decision criteria to assist the rater. Ratings from the scale correlated well with objective measures of hand activity level such as the amount of recovery time within a cycle and the number of exertions performed per second ($r^2 = 0.58$ and 0.53, respectively). This rating scale has been incorporated by ACGIH Worldwide (9) in establishing threshold limit values (TLVs) of hand activity.

Despite their use in assessing exposure to postural and repetitive stresses, observational methods have not adequately addressed the assessment of forceful exertion. Only four methods of the 19 evaluated by Kilbom (2,10–12) used direct observation to quantify force, and those studies primarily focused on gross manual materials handling exertions such as lifting, not on the many other types of forceful actions such as applying grip force to a tool or applying pinch force to fasten components together. Furthermore, these methods typically quantify the forceful exertion based on the weight of the object handled. There are several shortcomings of this approach. First, it is difficult for people to assess the magnitude of forceful exertion in units of force or mass (i.e., kilograms, pounds, etc.) because human subjects are not "calibrated" for such units. For example, Wiktorin *et al.* (13) found it extremely difficult even for trained ergonomists to observe and differentiate between incidents when subjects handled light ($<$5 kg) and heavy ($>$5 kg) loads. Second, weight is not the only characteristic that affects the force a worker must produce, so the force demand of a task may be misrepresented by classifying it only by the weight of the object handled. Frictional characteristics between the hand and the work object, for example, are very important in determining the pinch force that must be exerted to hold an object (14). Also, a hand tool may be very lightweight but may require a high level of grip force to activate or engage. Likewise, the force demands to use power tools often are the result of mechanical reactive forces such as tool recoil or torque (15). Finally, physical units of force do not inherently provide an indication of how taxing the exertion is to the worker who performs it, which is presumably the motivation for obtaining the measurement. A given force level may be very demanding for a weak female to perform, while being very easy for a strong male.

Regardless of the inherent limitations of observational methods, little research has been performed to evaluate the use of observational rating techniques to quantify the magnitude of forceful exertion. Latko (7) used a simulated transfer task to compare EMG measurements of the forearm to observer ratings (0–10 scale). Ratings correlated reasonably well with peak EMG of the forearm muscles ($r^2 = 0.54$). However, EMG and the force produced by the hand (the quantity being rated) are not always collinear because of factors such as cocontraction and the sensitivity of the EMG-force relationship. Ketola *et al.* (16) also investigated the repeatability and validity of observational-based force assessment and found that observers significantly underestimated the occurrence of high-force applications, as measured by EMG.

In light of these studies, one objective of this experiment was to further evaluate, using direct force measurement, the use of observational rating to evaluate the accuracy and precision with which outside observers estimate the magnitude (in % MVC) of forceful upper extremity exertions. It is hypothesized that observers with a year or more of experience in performing ergonomic analysis would demonstrate more precision and accuracy than inexperienced analysts. Also, on the basis of the limitations of the few observational techniques that have been proposed, a secondary objective of this research was to conduct a parallel survey to assess the perceived force demands of activities of daily living. This list may be used in the future to augment both observational and psychophysical methods of force assessment and to provide health care providers with a benchmark list of activities that could be compared to the physical demand of work tasks. Such a list may be a useful tool for health care providers and injured workers to convey the force demands of work as well as to assess the reduced physical capacity of injured workers.

## METHODS

To accomplish the stated objectives, an experiment was conducted in which subjects simulated a range of tasks that varied with respect to the force demands. These sessions were videotaped and later analyzed by a group of outside observers who estimated the magnitude of the exertions, as a percentage of the test subject's maximum voluntary contraction (% MVC). In addition, as the subjects performed the controlled exertions, they were asked to identify activities of daily living they perceived as analogous in force demand as the test exertions.

### Equipment

The primary device used in this experiment was a work simulator (17,18) which was used to measure and control the force produced as subjects simulated common hand activities such as using a screwdriver, turning a steering wheel, and many others. The work simulator allows the experimenter to precisely control the resistance of the exertions.

### Subjects

Sixty-four subjects participated in the work-simulation part of the experiment. Fifty-five of the 64 subjects (85%) were students. The average age of the subject sample was 23.6 years (SD: 6.5, range: 19–55) and the sample consisted of 36 males and 28 females. Subjects were screened via questionnaire to ensure they were not currently suffering from or had a history of upper extremity musculoskeletal disorders. A separate group of eight people was selected to observe the videotaped clips of the work sessions in order to estimate the magnitude of the exertions. Four of the eight analysts had experience (one year or more) in ergonomic evaluation, while the other four had no prior experience.

**Table I.** Summary of Maximum Strength Data

| Task | Strength | | | |
|---|---|---|---|---|
| | Female | | Male | |
| | Mean | SD | Mean | SD |
| Pinch* | 16.2 | 2.6 | 24.3 | 4.5 |
| Grip* | 49.8 | 13.9 | 91.1 | 18.6 |
| Supination** | 43.5 | 6.9 | 77.6 | 12.9 |
| Pronation** | 42.9 | 11.5 | 73.4 | 18.7 |
| Key** | 19.8 | 3.9 | 28.8 | 4.4 |
| Screwdriver** | 27.9 | 6.5 | 42.7 | 9.5 |
| Knob** | 27.0 | 6.6 | 43.7 | 14.0 |
| Push* | 19.9 | 4.7 | 34.5 | 10.7 |
| Pull* | 23.9 | 6.9 | 37.9 | 11.9 |
| Press* | 16.5 | 2.6 | 29.5 | 9.1 |
| Overhead* | 41.1 | 10.5 | 73.0 | 17.5 |
| Wheel** | 412.2 | 96.0 | 746.8 | 144.8 |

*Note*. Single asterisk indicates strength in pounds; double asterisks indicate strength in inch-pounds.

### Experimental Procedure

Twelve exertions were selected to encompass a wide range of upper extremity muscles. These exertions were power grip, pinch grip, pronation, supination, push, pull, overhead press, press down, turning knob, turning a key, turning screwdriver, and rotating a large wheel (18). Prior to performing the submaximal exertions and survey, maximum static strength was obtained for each type of exertion. These strength measurements are presented in Table I. For each task an exertion was performed for each of three force levels: low, medium, and high, representing the lower, middle, and upper thirds of the subjects' static strength for that particular task. The force levels were presented in random order for each simulated task and the tasks were performed in random order. While performing each exertion, subjects were asked to "name activities of daily living that require approximately the same level of effort," and their responses were recorded. Experimental sessions were videotaped for 32 of the 64 subjects. Thirty-six clips were randomly selected for each of the three force levels, for a total of 108 clips. These clips were distributed to the observers who were asked for each to estimate the magnitude of the peak forceful exertion performed, as a percentage of the worker's maximum strength.

## RESULTS

### Observer Estimation

Figure 1 presents the average and standard deviation of the error (estimate–actual) associated with observer estimation of exertion magnitude. For this experiment, average error is used as a measure of accuracy and standard deviation is used as a measure of precision. No significant difference in accuracy was found between the experienced group of observers and the inexperienced group, $F((1{,}860) = 0.22$, $p = 0.64)$. In general, there was a tendency to bias the estimate toward the mean (50% MVC). For the low force levels

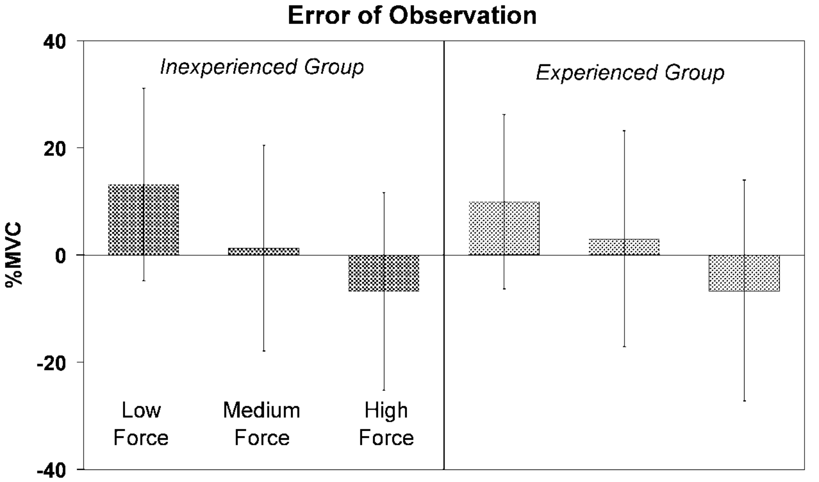


**Fig. 1.** Error of perceived exertion (estimated-actual) for observational assessment. The error bar depicts the mean ± one standard deviation.

(<34% MVC), observers demonstrated a strong tendency to overestimate the magnitude of the exertion, as the mean error was positive (13.2 and 10.0% MVC for inexperienced and experienced subjects, respectively). Conversely, for the high force levels, observers demonstrated a tendency to underestimate the magnitude of the exertion, as the mean error was negative (−6.8 and −6.7% MVC for inexperienced and experienced subjects, respectively). For the medium level of force, no strong tendency was observed, as mean error was near zero (1.3 and 2.9% MVC for inexperienced and experienced group, respectively). The differences in mean error between low, medium, and high levels of exertion were all statistically significant ($\alpha = 0.05$). The standard deviation (precision) was very high, ranging from 16.2–20.7% MVC across all conditions.

## Survey Responses

Table II presents the tallied sums of the subject responses after performing low, medium, and high levels of force for 12 types of upper extremity exertion. Only activities listed by at least three subjects (5% response rate) are reported. A total of 201 activities were reported, of which 59 (29%) were identified by at least three of the subjects. These 59 activities represent 79% of the total number of responses (681). The most frequently cited activities are listed from the top of the table in descending order. Of the 59 activities cited by at least three subjects, 12 (20%) were listed in only one of the three categories, 40 (68%) were listed in two adjacent categories (i.e., low and medium or medium and high), and seven (12%) were listed in all three categories. In no case was an activity listed as low and high without also being listed as medium. From the tallied responses in Table II, a weighted "score" was computed for each activity by multiplying the frequency of each response by the midpoint of each of the three force intervals. Thus, for the low level of force (<34% MVC), the average value was 17% MVC. Similarly, the values for the medium (34–67% MVC) and high (>67% MVC) levels of force were 50% and 83%

**Table II.** Summary of the Range of Force Classifications for Activities of Daily Living[a]

| Low | Medium | High |
|---|---|---|
| Driving/steering (23) | Driving/steering (6) | Driving/steering (2) |
| Turning doorknob (15) | Turning doorknob (10) | |
| | Opening pickle jar (11) | Opening pickle jar (12) |
| Writing (19) | Writing (3) | |
| Screwdriver (2) | Screwdriver (14) | Screwdriver (6) |
| | Weight lifting (2) | Weight lifting (20) |
| Closing/opening door (13) | Closing/opening door (8) | |
| Typing (18) | Typing (1) | |
| Brushing Teeth (17) | | |
| | Shoveling snow (9) | Shoveling snow (8) |
| | Moving furniture (1) | Moving furniture (14) |
| Washing dishes (10) | Washing dishes (5) | |
| Opening soda bottle (4) | Opening soda bottle (8) | Opening soda bottle (2) |
| Unlocking door (9) | Unlocking door (4) | |
| Vacuuming (6) | Vacuuming (5) | |
| Faucet knob (9) | Faucet knob (2) | |
| Sweeping floor (4) | Sweeping floor (6) | Sweeping floor (1) |
| Opening drawer (8) | Opening drawer (1) | |
| | Rowing canoe/boat (4) | Rowing canoe/boat (5) |
| Raking leaves (1) | Raking leaves (6) | Raking leaves (2) |
| Mousing (8) | | |
| | Push-ups (3) | Push-ups (5) |
| Making bed (5) | Making bed (3) | |
| Shaking hands (4) | Shaking hands (4) | |
| Opening car door (3) | Opening car door (4) | |
| Radio dial (7) | | |
| | Water skiing (2) | Water skiing (5) |
| Eating with fork/spoon (7) | | |
| Pumping gas (5) | Pumping gas (2) | |
| Closing appliance door (5) | Closing appliance door (1) | |
| Brushing hair (4) | Brushing hair (2) | |
| Pushing grocery cart (3) | Pushing grocery cart (3) | |
| Stapling (2) | Stapling (4) | |
| | Carrying grocery bags (3) | Carrying grocery bags (3) |
| | Sawing wood (3) | Sawing wood (3) |
| Wiping counter (5) | Wiping counter (1) | |
| Mopping floor (1) | Mopping floor (5) | |
| | Opening garage door by hand (4) | Opening garage door by hand (1) |
| Studying/reading (5) | | |
| Changing light bulb (4) | Changing light bulb (1) | |
| | Scrubbing floor (4) | Scrubbing floor (1) |
| | Stuffing suitcase (2) | Stuffing suitcase (3) |
| Scissors (3) | Scissors (2) | |
| Hammer (1) | Hammer (3) | Hammer (1) |
| | Opening car/truck hatch (4) | |
| Ironing (3) | Ironing (1) | |
| Stove knob (4) | | |
| | Scraping ice (3) | Scraping ice (1) |
| Tying shoe (3) | Tying shoe (1) | |
| | Pushing car (4) | |
| Mowing lawn (1) | Mowing lawn (1) | Mowing lawn (2) |
| | Changing tire (1) | Changing tire (3) |
| Car ignition (4) | | |
| Squeezing shampoo bottle (3) | Squeezing shampoo bottle (1) | |
| | Starting lawnmower (3) | |
| | Manual car window (3) | |
| Wire cutters (1) | Wire cutters (2) | |
| | Jack up car (1) | Jack up car (2) |

[a] Only activities listed by at least 5% of the subjects are reported. The number in parentheses indicates the frequency of the response.

MVC, respectively. As an example, the activity "Opening Pickle Jar" had 11 responses for "medium" and 12 responses for "high." The average score for this activity was thus computed as follows:

$$\text{Average Score} = \frac{(11 \times 50\%\ \text{MVC}) + (12 \times 83\%\ \text{MVC})}{(11 + 12)} = 67.2\%\ \text{MVC}$$

Table III summarizes the average scores for all the activities listed in Table II. On the basis of the average score, each activity was grouped into one of five intervals of equal width on the 0–100% MVC scale. Thus, the first interval is 0–20% MVC, the second interval is 20–40% MVC, etc. These intervals were assigned categorical values of very low, low, medium, high, and very high. As an example, the "Opening Pickle Jar" activity, with an average score of 67.2, is classified in Table III as an activity requiring a "high" amount of force.

## DISCUSSION

### Observer Estimation

In this experiment, it was hypothesized that observers with experience in conducting ergonomic analysis would more accurately and precisely evaluate force than an untrained group of observers. Training has been shown to have a significant improvement in both precision and accuracy of exertion estimation for subjects who verbally estimate the magnitude of upper extremity exertion that they themselves produce (19). However, this was not validated for observational assessment, as no significant difference was observed between estimation error for an experienced and an inexperienced group of analysts. These results are consistent with Ketola *et al.* (16), who found that inexperienced observers identified high levels (binary measurement) of force as accurately as "expert" observers.

Despite these results, it should not be generalized that training is unimportant in employing observational methods of ergonomic assessment. The variable that participants were asked to observe and rate for this experiment, forceful exertion, may be difficult to assess as suggested by these results, but it is a quantity that is relatively straightforward to define and understand. On the other hand, a variable such as posture is a variable that is much more complicated to define, as there are many body parts and joints that must be looked at simultaneously. For example, RULA is used to evaluate over a dozen specific joints and postures (4,5). In this case, due to the potential ambiguity of the process, it is likely that training is very important in order to acclimate users to the rating system.

In this study observers tended to overestimate low force levels and underestimate high force levels (Fig. 1). As a result, observers tended to bias their ratings toward the mean (50% MVC), as the average error in estimating medium level forces was near zero; the average error in estimating low forces was positive; and the average error in estimating low forces was positive. While the average error for the medium force levels in this study was near zero (1.3 and 2.9% MVC), the precision of the estimate was very poor as indicated by the high standard deviation (range: 16.2–20.7% MVC). To demonstrate the effect of poor precision, consider an observational estimate of 50% MVC. On the basis of the average error and standard deviation found in this study, the 90% confidence range of the actual force would

**Table III.** Summary of the Average Force Classification for Activities Identified by Subjects[a]

| Very low (0–20%MVC) | Low (20–40%MVC) | Medium (40–60%MVC) | High (60–80%MVC) | Very high (80–100%MVC) |
|---|---|---|---|---|
| Typing (19) | Driving/steering (31) | Screwdriver (22) | Opening pickle jar (23) | Weight lifting (22) |
| Brushing teeth (17) | Turning doorknob (25) | Opening soda bottle (14) | Shoveling snow (17) | Moving heavy furniture (15) |
| Opening drawer (9) | Writing (22) | Sweeping floor (11) | Rowing boat/canoe (9) | Pushing car (4) |
| Mousing (8) | Closing/opening door (21) | Raking leaves (9) | Push-ups (8) | |
| Radio dial (7) | Washing dishes (15) | Mopping floor (6) | Water skiing (7) | |
| Eating with fork/spoon (7) | Unlocking door (13) | Opening garage door (5) | Carrying grocery bags (6) | |
| Studying/reading (5) | Vacuuming (11) | Scrubbing floor (5) | Sawing wood (6) | |
| Stove knob (4) | Faucet knob (11) | Hammering (5) | Stuffing suitcase (5) | |
| Car ignition (4) | Making bed (8) | Rear hatch of car/truck (4) | Changing tire (4) | |
| | Shaking hands (8) | Scraping ice (4) | Jack up car (3) | |
| | Opening car door (7) | Mowing lawn (4) | | |
| | Pumping gas (7) | Starting lawnmower (3) | | |
| | Opening appliance door (6) | Manual car window (3) | | |
| | Brushing hair (6) | | | |
| | Pushing grocery cart (6) | | | |
| | Stapling (6) | | | |
| | Wiping counter (6) | | | |
| | Changing light bulb (5) | | | |
| | Scissors (5) | | | |
| | Tying shoe (4) | | | |
| | Ironing (4) | | | |
| | Squeezing shampoo bottle (4) | | | |
| | Wire cutters (3) | | | |

[a]The number in parentheses is the number of responses given by the 64 subjects who participated in the survey.

be very wide (20.1–85.7% MVC), making the estimate not very useful for determining the force required of the task being analyzed.

There is considerable difference in the error that is to be expected when the subjects who perform the exertion estimate the magnitude themselves versus when outside observers estimate the magnitude. Marshall *et al.* (19) found that untrained subjects tended to overestimate the forces they themselves produced, regardless of force level. Likewise, Wiktorin *et al.* (13) found subjects consistently produced push/pull forces that were larger than requested, regardless of force level. However, the most important difference between these methods is that individuals, trained or untrained, are much more accurate and precise when estimating forces that they themselves produce than when observing and estimating the forces that others produce. For example, suppose an observer estimates an exertion to be 60% MVC. From this study, the 90% confidence interval of the actual force would be very large, 24–90% MVC. From Marshall *et al.* (19) if an untrained individual estimated his own exertion to be 60% MVC, the 90% confidence interval of the actual force would still be quite large, 11–70% MVC. However, if the individual received training prior to estimating the force, this confidence interval would significantly improve to 40–86% MVC. Since no effect of experience was observed in this experiment, it does not seem likely that such an improvement in accuracy or precision could be expected for observational assessment.

## Visual Cues of Force

Perhaps the scarcity of observational methods of force assessment is due to the difficulty associated with observing and describing force. These results provide evidence that precision, in particular, is poor for observational assessment. In contrast to posture and hand activity, which may be observed on the outside of the body, forceful exertions are the result of muscles contracting beneath the surface of the skin. As a result, forceful exertions often lack conspicuous visual cues, making it difficult for an observer to discriminate between different levels of force, especially for static exertions. For example, Fig. 2 shows a person gripping a handle at two extreme levels of force. The picture on the right shows the subject gripping with near maximal force while the picture on the left shows the same subject gripping at a very low level of exertion. It is difficult to see from a static photograph of the hand much difference between these two extremes, and is even more difficult to differentiate between intermediate levels that are close in magnitude.

Video footage, however, provides subtle but important cues related to the subject's body language that may be used to assess force. On the basis of the video clips obtained in this experiment, visual characteristics of forceful exertion were identified and compiled to help observers estimate the magnitude of forceful upper extremity exertion. These visual cues are described below:

1. Smoothness or Fluidity of Exertion—At a low level of force, exertions appear smooth, fluid, and sometimes "effortless." At maximal levels of force, exertions appear somewhat erratic, jerky, and/or difficult to control.
2. Contorted or Unnatural Posture—As the force demands of a task increase, the worker may change or adapt his/her posture to utilize larger muscle groups or to maximize his/her mechanical leverage, making the action appear awkward, or less natural than it would at the lower force level.

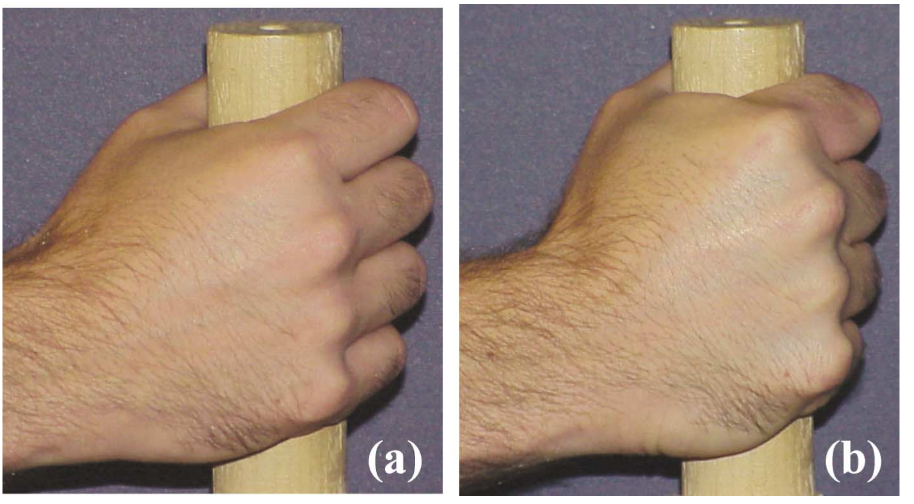


**Fig. 2.** Subject gripping a handle with low and high grip forces. (a) Subject grips the handle enough to just hold the handle. (b) Subject grips the handle with a force near maximum. It is difficult to ascertain the magnitude of the forceful exertion from the static photograph.

3. Use of Body Weight—As the force demands of a task increase, so may the worker increasingly use his/her body weight to overcome the forceful demands of the task. This includes leaning into an exertion or "throwing" the worker's weight into the exertion.
4. Strained Facial Expression—For low levels of force, the worker generally appears normal or relaxed. During highly forceful exertions, however, the worker may exhibit a strained expression, a grimace, or a look of concentration, discomfort, or pain. Such expressions may easily be observed in watching weight lifters strain to lift very heavy loads.
5. Bulging Muscles—For high levels of force, workers often exhibit bulging muscles. However, caution should be exercised because bulging muscles may also be observed for highly repetitive exertions of low force. Obviously the presence of bulging muscles is largely dependent on the physical conditioning of the worker being observed as well as the worker's clothing.
6. Repositioning of Hand—For high levels of force, the worker may reposition or relax his hand to relieve it of the high mechanical contact stress placed on the palm or fingers.

The visual cues of force suggested here are meant only as rough heuristics to use when observing a person perform the activity or task of interest. On the basis of observation of 64 subjects performing 12 exertions each, there is considerable variation in the way tasks are performed and in the visual cues of body language that result and it is not possible to give clear-cut ranges in force magnitude for the dynamic characteristics put forth here. Generally speaking, it is easy to perceive the differences between very high and very low levels of force, based on these characteristics. However, it becomes challenging for an outside observer to discern between intermediate levels of force.

## Survey Responses

As Table II illustrates, considerable variability exists in the perception of the force requirements of activities of daily living. A vast majority (88%) of the activities listed were placed into multiple categories. There are at least four contributing factors to this variation. First, variation exists with respect to the accuracy and precision with which subjects are able to estimate and perceive the magnitude of the exertion they produce (19), meaning subjects tend to misjudge the intensity of the task. Secondly, variation in human strength results in a broad range in the % MVC required to perform the activity. People have different strength capabilities, and an activity that requires a specific amount of force represents a lower % MVC for a strong individual than for a weaker individual. In some cases, a worker may not even be physically capable of performing a task that requires force exceeding his/her strength (100% MVC). Thirdly, the activities themselves vary in the amount of force required. For example, the force required to open containers such as bottles or jars varies depending on factors such as the tightness of the seal, the diameter of the lid, and the frictional characteristics of the lid material (20,21). Likewise, the force required to pull open a door depends on factors such as the weight of the door and the friction of the hinges.

As an example of how variability in task demands and human strength affect the range of % MVC required of a task, the pull force required to pull open inside and outside doors located in public buildings was measured using a standard push/pull force gauge. The pull force for 20 doors was measured and was approximately normally distributed with a mean of 9.5 pounds and a standard deviation of 5.1 pounds. These doors varied somewhat with respect to the handle design, but all the doors had tubular metal handles approximately 3/4" in diameter. The smallest opening force measured was 2.5 pounds and the largest was 22.0 pounds. It should be noted that these values do not include the force required to manipulate the handle to disengage the latching mechanism. Accordingly, the 5th percentile female and 95th percentile male pull-strength values from this experiment are 12.8 pounds and 56.8 pounds, respectively. Expressed as units of % MVC, the lower bound is the ratio of the low (5th percentile) pull force of the doors to the high (95th percentile) strength value, and the upper bound is vice versa. As a result, the lower and upper bounds are 5% (5.1/56.8) and 58% MVC (12.8/22.0) respectively, for pulling open a door. The average % MVC is 31%, as calculated using the average pull force demands of the doors surveyed (9.5 pounds) and the average pull strength (31 pounds, males and females pooled).

In comparing this result to the results of the survey performed in this experiment, the calculations and the range of responses are consistent. Based on the calculations and the three force categories used during the experiment (low, medium, and high), the force requirements for opening a door range from very "low" (5% MVC) to the upper side of "medium" (56.8% MVC). Likewise, in categorizing the activity "closing/opening door," 13 people categorized it as "low," while eight people categorized it as "medium." Also, the average force requirement (31% MVC) was consistent with the average classification of the activity (between 20 and 40% MVC, or "low") as shown in Table III.

Data on the force requirements for other activities are relatively scarce. However, in his study of acceptable force exerted while opening consumer products, Berns (20) derived from packaging industry information, the "typical" force required to open a large jar and found this value to be 40 inch-pounds of torque (no standard deviation reported). From the strength measurements performed in this experiment, the 5th percentile female and 95th percentile male strength values are 16.1 inch-pounds and 66.8 inch-pounds, respectively. Thus, the lower bound for % MVC is 60% (40/66.8) and the upper bound is 100%, as 40 inch-pounds exceeds the capacity of a 5th percentile female. This range of % MVC for opening a jar (60–100% MVC) is consistent with the range of categories specified in the survey in that 11 subjects classified the activity as "medium" force while 12 subjects classified it as "high."

Despite these two examples of agreement between survey results and objective force measurements, it appears that some of the activities in Table III may be classified too high. For example, brushing hair usually only requires a small amount of force, yet the weighted average was 28% MVC. Also, even though many people can steer a car with only one finger, the weighted average was 27% MVC. These seemingly inflated values may be the result of the scoring method used. In weighing "low" force activities by the average level of 17% MVC, the lowest score that can be obtained is 17% MVC assuming all responses classified the activity as "low."

While further validation of these results is needed, very few quantitative data exist to describe the force demands of activities of daily living. Researchers have investigated the amount of force people exert to perform activities simulated in the lab (20–22), but since the task demands typically remain constant for laboratory experiments, the variability from these types of studies reflects the variability of the force people apply, not the variability of the outside factors that make the task more or less difficult. While some technology has been developed to facilitate such measurements in the field (23,24), more work is needed in this area to make direct force measurement accessible on a widespread basis. Such information could be used to obtain further validation of the results obtained in this study.

## Use of Survey Results in Rehabilitation Settings

The results of the survey component of this study have at least two potential applications for a clinical or rehabilitation setting. First, the list provides a means by which patients may convey to health care providers the approximate force requirements of their occupational tasks. The results of this study and others (16,19) suggest that the worker him or herself is more able than an outside observer at providing reliable information about the force requirements of their job. By using the scale in Table III, a patient when asked about the force required of his/her work, could describe it as being similar to one or more of the activities in the table. This would provide at least some estimate of the force the worker exerts, which may be useful in evaluating the patient's condition or prescribing a course of rehabilitation.

Second, the survey provides a potential tool for health care providers to quickly and unobtrusively assess the diminished strength of patients suffering from physical injuries or illnesses. While strength testing likely offers a more objective and definitive measurement of capacity, the measurement itself may aggravate the condition from which the patient already suffers. The scale presented in Table III may be used as a baseline for comparing how injured workers perceive the same activities in terms of the physical force required. The survey conducted in this study utilized young, healthy subjects free of musculoskeletal pain or discomfort. Injured workers could be given the same list of activities and asked, in light of their present physical condition, to rate the physical demand of each activity as very low, low, medium, high, and very high. For someone with diminished strength the activities listed in Table III would likely shift upwards to reflect the reduced capacity of the individual. For example, while opening a pickle jar, on average, may be considered a "high" force (60–80% MVC) task for the healthy subjects in this study, a worker with an upper extremity musculoskeletal disorder may consider the demands to be "very high" or even beyond his/her capability. Comparing the patient's ratings of these activities to the healthy baseline (Table III) may provide the health care provider with useful information about the patient's disability. Furthermore, the benefits of using the scale in such a way is that it would take little time and the patient would forego having to produce a potentially aggravating exertion. Application of these results in a clinical or rehabilitation setting has not yet been conducted.

## CONCLUSION

In this study, outside observers demonstrated poor precision when estimating the magnitude of forceful exertion and tended to err in the direction of the mean (50% MVC). Furthermore, experience of the analyst was not shown to significantly improve the precision or accuracy of the estimate. Because forceful exertions often lack conspicuous, visual cues that indicate the magnitude of the exertion, it is recommended that the individuals who actually perform the activity provide feedback when evaluating force. In a rehabilitation or clinical setting the list of activities generated from the survey performed in this study may be a useful tool by which injured workers communicate the approximate magnitude of the force required of their work tasks as well as for evaluating the extent to which the strength of an injured worker is diminished.

## ACKNOWLEDGMENTS

This work was funded, in part, by National Institute on Disability and Rehabilitation Research of the United States Department of Education under Grant No. H133E980007. Matthew Marshall was supported by Grant No. T42-CCT510428-08 from the National Institute for Occupational Safety and Health.

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