THE USE OF FORCE MATCHING TO QUANTIFY JOB DEMANDS

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Physical demands descriptions and ergonomics assessments require the measurement or estimation of hand force demands, including push force against an object, grip force, and pinch forces. Some grip or pinch forces cannot easily be measured directly. Previous research has shown that, given a consistent and logical "force matching" protocol (Bao and Silverstein, 2005), workers can consistently replicate task forces using a hand dynamometer. The purpose of this investigation was to identify a protocol for practical, consistent estimation of task hand forces using force matching. Two force matching protocols were evaluated with two tools. The results indicate that using a detailed force matching protocol is comparable to measured force values. When force matching in an applied setting, the ergonomist should provide workers with as much detail as possible regarding the force matching procedure, and should ensure that the force matching protocol matches the job design.

Key words: Job demands, force matching, protocol

L'UTILISATION DE L'ADAPTATION DE LA FORCE POUR QUANTIFIER LES EXIGENCES DES TÂCHES

Pour décrire les exigences physiques et faire des évaluations ergonomiques, il faut avoir la mesure ou l'estimation de la force de la main, notamment la poussée contre un objet, la force de préhension et la force de pincement. Certaines forces de préhension ou de pincement ne sont pas faciles à mesurer directement. Des recherches antérieures ont démontré que, munis d'un protocole constant et logique en « adaptation de la force » (Bao et Silverstein, 2005), les travailleurs peuvent, de façon constante, reproduire les forces liées aux tâches en utilisant un dynamomètre de préhension. L'objectif de cette investigation vise à déterminer un protocole pour l'estimation constante et pratique de la force de la main pour une tâche donnée en utilisant l'adaptation de la force. Nous avons évalué deux protocoles d'adaptation de la force à l'aide de deux outils. Les résultats indiquent que l'utilisation d'un protocole d'adaptation de la force détaillé se compare aux valeurs de force mesurées. Dans un milieu où l'adaptation de la force s'applique, l'ergonome pourra très bien renseigner les travailleurs sur la procédure d'adaptation de la force, et ainsi s'assurer que le protocole d'adaptation de la force correspond à la conception des tâches.

Mots clés : conception des tâches, adaptation de la force, protocole

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1.0 INTRODUCTION

Measured forces are often used to determine the suitability of a task for an injured worker, and to evaluate musculoskeletal disorder risks. Although most force measurements (such as pushing and pulling) can be measured directly with a force gauge, tasks which require gripping and pinching often cannot be measured using this approach. Grip or pinch force can be assessed indirectly using psychophysical methods such as having the worker rate the grip effort on a visual analog scale, or using a hand dynamometer to allow the worker to replicate the force exerted during the task. Literature shows inconsistent evidence regarding the validity of this method, which could be attributed to the variability in testing protocol (Dale et al., 2011). A laboratory based study conducted by Bao and Silverstein (2005) found force matching using a hand dynamometer to be a reliable and valid method of obtaining grip and pinch forces, when the protocol is detailed and well explained to the operator. Other factors shown to affect grip force matching using a hand dynamometer include gender, age and level of force required (King and Finet, 2004). Studies have shown inconsistent findings regarding the level of force and variability, with some studies reporting increased variability with low levels of force (Kumar et al., 1997; Lowe, 1995) and others reporting higher variability when force matching using high levels of force (King and Finet, 2004; Bao and Siverstein, 2005). The amount of detail in the instructions has also been documented in the literature as an important factor to consider when implementing a force matching protocol. Bao and Silverstein (2005) found that by providing more detailed instructions to the participants, and giving practice trials, they were able to obtain more accurate results with less variability than using simple concise instructions. The purpose of this study is to identify and evaluate a force matching protocol which takes into consideration factors shown to increase variability in force matching results, and provides sufficiently detailed instructions to the worker, to increase validity and repeatability of force matching. Two experiments were performed to assess concise and detailed force matching protocols. Experiment 1 was a field study, conducted with maintenance workers at conservation areas. Experiment 2 replicated a task performed in a workplace, and was conducted in an office setting using office workers.

2.0 EXPERIMENT 1

2.1 Force Measurement

The force required to compress the trigger of a litter picker tool (Figure 1) was measured using a calibrated linear strain gauge (MF-50kg series, Shimpo Instruments, Itasca, IL, USA). Five consecutive measurements of full handle depression force were recorded in kilograms using the tool in the same manner as the tasks. The maximum and minimum recorded values were dropped, and the mean of the three remaining values was calculated. data collection protocol. The depression force measurement was considered to be the “gold standard” and was used to evaluate the validity of two force matching protocols: a concise force matching protocol, and a detailed force matching protocol.

2.2 Participants

Six (6) male and four (4) female maintenance workers, ages 17-29, participated in this study. The participants had no history of hand injuries within the past 12 months. Experienced maintenance staff members were recruited for this study, and all had used the litter picker tool recently during the course of daily duties. The participants were not familiar with force matching purpose or protocols prior to the study.

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2.3 Apparatus

The tool used to evaluate the force matching protocols was a “litter picker” (Grip n’ Grab, Ettore, Alameda, CA, USA) which is commonly used by maintenance personnel at a seasonal camp ground (Figure 1). The operator uses the apparatus to pick up litter on the ground by squeezing the trigger on the handle, which closes the claw around the litter. The grip span of the litter picker used in the study was 10.0 cm when open and 6.5 cm when depressed. A power grip is used to grip the handle with typically 2-3 fingers on the trigger. Force matching for this task was performed using a calibrated Jamar Hydraulic Hand Dynamometer (Lafayette Instrument, USA). The participants were asked to repeatedly pick up plastic pop bottle caps from the ground and place them into a box (figure 2).

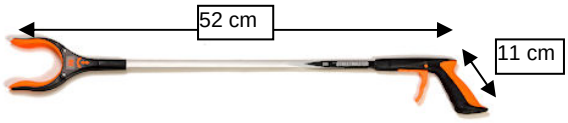

Figure 1: Litter picker tool (0.2 kg)

Figure 2: Participant using the litter picker

2.4 Concise Force Matching Protocol

The concise force matching protocol was based on the procedure used in McGorry et al. (2004). The participants were instructed to grip the hand dynamometer with the same level of force used to grip the object. The grip width of the hand dynamometer was matched to the grip width of the tool when the trigger is compressed. The force matching was performed immediately after completing the task, and was repeated 3 times, with the Participant repeating the task between each trial. The time between the trials was determined by the participant.

2.5 Detailed Force Matching Protocol

The experimenter instructions for the detailed force matching protocol are described below:

Operator Selection and Training

- When possible, select operators with lower strength capabilities, to mitigate the tendency for stronger workers to apply more grip force than necessary to complete the task.
- Allow the operator to measure his/her own strength, and practice with the hand dynamometer before collecting data, so s/he is comfortable with the equipment.
- Introduce the force matching procedure: Explain to the operator that you want to determine how tightly s/he grips an object or tool. Ask the operator to perform the gripping task with the minimal required force, and to memorize how much force they are using. Ask the operator to grip the hand dynamometer with the same force as s/he uses on the job. Where appropriate, let the operator know that you will be collecting worst case, typical, and best case forces to account for variations in object/tool quality.

Force Measurement Device Setup

- Use a hand grip dynamometer for gripping actions and wide pinching actions. Use the pinch gauge for pinching actions only (i.e. thumb vs. fingers).
- Adjust the grip width of the hand dynamometer to match the grip width of the object/tool.
- Position the hand grip dynamometer/pinch gauge at the same relative position (height and reach) and angle/orientation as the object/tool would be typically used. This may entail creating obstacles or mounting the gauge.
- Orient the scale to face away from the operator to reduce within-Participant bias.

Force Measurement

- Have the operator perform the actual task.

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- Have the operator position his/her hand/fingers as similar as possible to how he/she handles the object/tool. For example, if s/he extends the index finger while using the actual tool, have him/her imitate this posture while gripping the hand dynamometer.
- Support the weight of the force gauge if the tool that the operator uses is light.
- Ask the operator to imitate the typical force required to grip/pinch.
- Repeat the trial protocol 5 times. Allow the participant to return to his/her job between each trial.
- Repeat trial protocol for *maximal* and *minimum* forces, where appropriate. For example if the tool grip is slippery, on occasion, simulate the scenario and record the grip forces.

2.6 Data Analysis

A paired *t*-test ($\alpha = 0.05$) was used to compare the detailed and concise force matching protocol results. One-sampled *t*-tests ($\alpha = 0.05$) were used to compare the concise force matching and the detailed force matching protocols to the actual required grip force. The mean and standard error was calculated for both force matching protocols.

2.7 Results

The measured grip force required to compress the litter picker trigger was 0.9 kg. The grip force using the concise protocol ($p<0.001$) and detailed protocol ($p=0.039$) were significantly greater than the measured force. The force for the detailed force matching protocol (1.97 ± 1.52 kg) was significantly less ($p=0.001$) than the concise force matching protocol (8.39 ± 5.37 kg) (Figure 3).

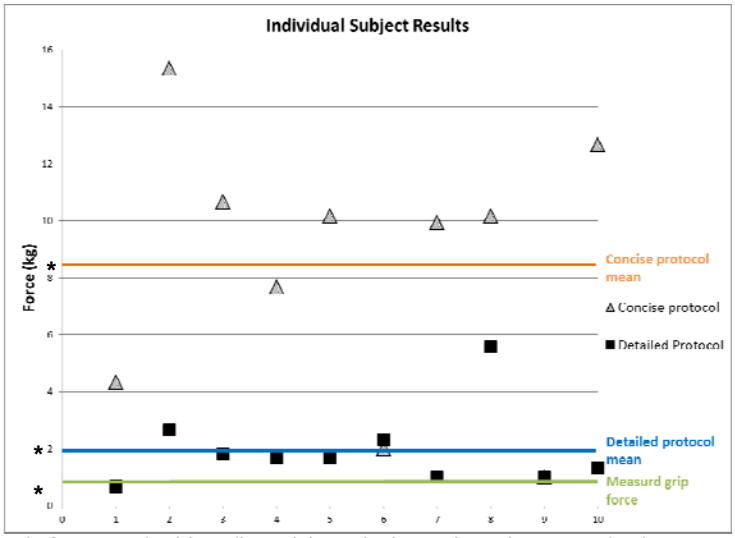

Figure 3: Individual grip force required for a litter picker gripping task, and measured using a concise and a detailed force matching protocol. * denotes statistical significance.

3.0 EXPERIMENT 2

In Experiment 1, the measured force to grip the trigger of the litter picker to hold a bottle cap was low. In their daily duties, when the litter weight and dimensions vary, workers may use more force than required to grip the litter picker. Therefore, when asked to replicate task demands, participants may have overestimated the force required to grip the trigger, in spite of the directions to estimate “minimum” force requirements. For Experiment 2, a tool requiring a greater, and more consistent grip force, was selected. The task also required a more consistent and controlled vertical and horizontal reach, which allowed the experimenters to replicate the task during force matching more precisely.

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3.1 Force Measurement
The force required to compress the paint brush clip was also measured using a linear strain gauge (MF-50kg series, Shimpo Instruments, Itasca, IL, USA). The force measurement protocol was the same as in Experiment 1. The depression force measurement was again considered to be the “gold standard”, and was used to evaluate the concise and detailed force matching protocol.

3.2 Participants
Nine (9) female and nine (9) male office workers, ages 23-60, participated in this study. The participants also had no history of hand injuries within the past 12 months. The participants were not familiar with the purpose of force matching or the force matching protocols prior to the study.

3.3 Apparatus
A paint brush clip (Paint Can Clip, Power Fist, Taiwan) was used to evaluate the force matching protocols (Figure 4). The grip span on the clip was 4.5 cm with the aperture closed, and 1.5 cm with the aperture open. A two finger chuck pinch was used to open and close the clip. Force matching for this task was performed using a Jamar Hydraulic Pinch Gauge (Sammons Preston Inc., USA). The participants were instructed to compress the clip, and affix the clip to a 2 cm wide surface at a height of 181 cm and a forward reach of 35 cm (Figure 5). Participants were given time to practice the task prior to introducing the force matching protocol.

Figure 5: Participant gripping paint brush clip

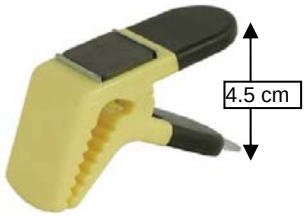

Figure 4: Paint brush clip (<0.1 kg)

3.4 Detailed and Concise Force Matching Protocols
The detailed and concise force matching protocols were consistent with those used in Experiment 1.

3.5 Data Analysis
A paired *t*-test ($\alpha = 0.05$) was used to compare the detailed and concise force matching protocol results. One-sampled *t*-tests ($\alpha = 0.05$) were used to compare the both the concise force matching protocol and the detailed force matching protocol to the actual required grip force. The mean and standard error was calculated for both force matching protocols.

3.6 Results
The measured grip force required to compress the clip was measured as 4.5 kg. The grip force using the concise protocol (6.4 ± 1.54) was significantly higher than the grip force using the detailed protocol (4.9 kg ± 1.18) ($p<0.001$) and the measured grip force ($P<0.001$). The detailed protocol grip force was not statistically different from the measured force ($p=0.147$) (Figure 4).

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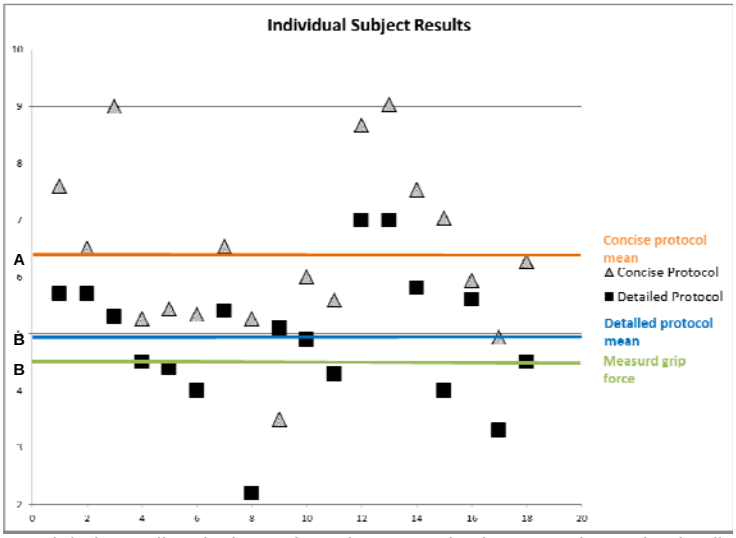

Figure 4: Grip force used during a clip gripping task, and measured using a concise and a detailed force matching protocol. A/B denote two levels of statistical significance.

4.0 GENERAL DISCUSSION

Force matching is an essential technique when task grip forces cannot be directly measured. The goal of this study was to compare a concise force matching protocol and a detailed force matching protocol, and to evaluate each of these methods in comparison with the measured grip force for two different tools.

In both experiments, the detailed force matching protocol elicited lower grip force estimates than the concise force matching protocol. The detailed force matching protocol provided greater, and more descriptive instruction to the user which is beneficial, as increased procedural detail increases the accuracy and reduces variability of measurement (Bao & Silverstein, 2005). Significantly higher grip force estimates for the concise force matching protocol in Experiment 2 substantiate the strength of the detailed method. During the concise force matching protocol, participants were immediately asked to grip the hand dynamometer following the task of interest with minimal orientation and instruction, whereas during the detailed protocol, participants were given the opportunity to familiarize themselves with the hand dynamometer prior to the data collection. Since the handles of litter picker tool and clip compress upon gripping, participants may have expected the same feedback from the hand dynamometer. This may have caused over-gripping and increased both mean grip scores and variability of scores during the concise force matching protocol compared to the detailed force matching protocol.

During experiment 1, using the concise protocol, participants tended to position the torso, arm and wrist to achieve the greatest mechanical advantage, as the posture to grip the hand dynamometer was not controlled. If the posture used in the task was more awkward than the posture used during force matching, the worker may have inadvertently exerted more force on the hand dynamometer to achieve the same perceived effort.

Variations in finger placement on the hand dynamometer in Experiment 1 could have also increased the concise force matching protocol grip force. For the detailed protocol, participants were given clear instruction to match the hand posture and finger orientation used with the actual litter picker tool, whereas no specific instruction was given for the concise protocol. When using the full hand to grip the hand dynamometer during the concise protocol, compared to the 2-3 fingers used to grip the litter picker tool, participants may have increased their force-producing capability and over-gripped the hand dynamometer.

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While the primary goal of this study was to compare a detailed and a concise force matching protocol, both of these protocols must be evaluated in their ability to accurately and consistently simulate the actual required force of a gripping task. The measured force was significantly lower than the estimated force for both the detailed protocol (p<0.001) and the concise protocol (p=0.038) in Experiment 1. However, in Experiment 2 the detailed protocol accurately estimated the force required to grip the tool (p=0.147). The difference in results between the two experiments may be due to protocol limitations as described below.

4.1 Protocol Limitations

First, the measured grip force to compress the litter picker trigger (0.9 kg) was low, and low force demands have been previously reported to be more difficult to match (Kumar et al., 1997; Lowe, 1995). Also, workers may use more force than required to grip the litter picker when using the tool in their daily duties, and therefore the participants may have been unable to replicate the minimum force required to complete the task. This observation could lead to some discussion amongst ergonomists regarding whether the goal of the force matching procedure is to estimate the minimum required forces or the typical forces used. Second, the limited number of Participants in Experiment 1 may have resulted in the increased variability. Replicating Experiment 1 using a larger sample size might decrease measurement variability and present a better evaluation of the two force matched protocols compared to each other and to the actual required force. Third, performing Experiment 2 with experienced workers in a work place setting may have led to different results.

5.0 CONCLUSIONS

When performing force matching in an applied setting, workers must be provided with as much detail as possible regarding the force matching procedure, intent of collection, and the operation of the hand dynamometer. Participants should be allowed to familiarize themselves with the hand grip dynamometer prior to data collection in order to maximize the accuracy of the results obtained. Replicating comparable tool weight, postures, and grip type of the actual task is valuable in reducing response bias and increasing the ecological validity of the data collected. Ergonomists should be cautious of using force matching with tasks requiring low force output as employees are likely to over-grip. Perhaps a more appropriate way to estimate the force of such tasks would be to select workers with low strength capabilities, for the force matching, thereby giving an estimate of forces applied by the limiting user.

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