

## Short-term Changes in Upper Extremity Dynamic Mechanical Properties Associated with Power Hand Tool Use

R. G. Radwin  
M. E. Sesto  
T. G. Richard  
University of Wisconsin  
Madison, WI

This study investigated the relationship between repetitive eccentric exertions in power hand tool operation and upper limb mechanical properties including stiffness and inertial mass, and physiologic measures including localized pain, discomfort, and swelling. Tool parameters, including peak torque (3 Nm and 9 Nm) and torque build up time (50 ms and 250 ms), were controlled in a full-factorial design. Twenty-nine participants were randomly assigned to one of the four conditions and operated a pistol grip nutrunner four times per minute for one hour in the laboratory. An average decrease in stiffness (48%) and mass moment of inertia (60%) of the upper limb was observed immediately following pistol grip nutrunner operation. A previously developed dynamic tool operator model was used to predict resulting handle force and displacement, and the conditions associated with the greatest handle force and displacement demonstrated the greatest decrease in mechanical stiffness and inertial mass, and the greatest increase in localized discomfort.

### INTRODUCTION

Workers operating industrial power hand tools that generate impulsive reaction force, such as nutrunners, are frequently exposed to repetitive forceful eccentric muscle exertions during the torque build up phase. (Oh, Radwin and Fronczak, 1997; Oh and Radwin, 1998; Armstrong et al., 1999). Research has demonstrated that when all other factors are similar, tool handle displacement and reaction forces are generally greater for nutrunners with high peak torques and soft threaded fastener joints, than for low peak torques and hard joints (Oh et al., 1997; Oh and Radwin, 1998).

Decreased muscle stiffness has been previously reported following maximal eccentric exercise. Warren et al., (1993) reported a decline in tension and muscle stiffness in rat soleus muscle following eccentric exercise and suggested that this reduction was due to fewer attached cross bridges. Leger and Milner (2000) reported a significant decrease in stiffness following maximal eccentric exercise in male subjects. Similar results were found in our own studies where a decrease in stiffness (51%) and inertial mass (43%) was observed following submaximal eccentric exercise (Sesto, 2002).

The current experiment was conducted to evaluate the effect of varying eccentric activity associated with the actual operation of power hand tools, by varying peak torque and torque build-up time, on mechanical parameters of the forearm, including stiffness and inertial mass and physiological measures, including localized pain, discomfort, and swelling. An important motivation for conducting this experiment was to investigate if power tool

operation had an effect on mechanical and physiological properties of the forearm, similar to that observed for maximal controlled eccentric exertions previously reported.

Differences in the mechanical parameters of the dominant forearm associated with repetitive use of power hand tools, before, immediately after, and 24 hours following tool use were investigated. The overall hypothesis was that subjects experience a greater change in mechanical stiffness, viscous damping and inertial mass of the upper limb following operation of higher peak torque power hand tools than subjects operating power hand tools with lower peak torque output tools. Similarly it was hypothesized that subjects operating nutrunners with longer torque build-up times experience a greater change in upper limb mechanical properties than those operating tools with a shorter build up time.

### METHODS

The experiment was a mixed effects repeated measures 2x2 full factorial design. The fixed independent variables were peak torque and build up time. The levels of these variables are representative of those typically found in automotive assembly. Subjects operated an industrial pistol grip nutrunner set either at a high peak torque (9 Nm) or a low peak torque (3 Nm), and either a long build up time (250 ms) or a short build up time (50 ms) on a vertical work surface. The subjects were positioned so the shoulder, forearm and wrist were in a neutral position with the elbow flexed at 90°. The power hand tool was operated for 60 minutes at a rate of 4 times per minute. All subjects were inexperienced tool operators.

Participants were healthy young male volunteers (mean age = 24.45 years, SD = 6.59) recruited at the University of Wisconsin-Madison. Males were only recruited because it was observed in earlier studies that a floor effect was present for females such that reductions in stiffness and other mechanical parameters may be limited since their magnitude was too close to the stiffness of the apparatus used in the study.

A general health status questionnaire was administered to all subjects immediately prior to testing. Subjects reporting upper extremity symptoms or a history of injury or occupational use of power hand tools were excluded from testing. Subjects were asked to avoid exercise or recreational sports for three days prior to participation in the experiment and the duration of the experiment.

Subjects were randomly assigned to one condition, with a minimum of seven subjects in each condition. A total of 29 subjects were tested. Biomechanical, physiological variables and symptoms were measured prior to exercise, immediately following exercise, and again 24 hours later. Mechanical measures included muscle stiffness, viscous damping and mass moment of inertia. Physiologic measures included forearm circumference measurements and isometric MVC. A visual analog scale ranging from 0-10 (0 corresponding to "no pain", and 10 corresponding to "most pain") was used to assess forearm discomfort.

Subjects were tested on an apparatus designed for measuring mechanical properties of muscles, stiffness and mass moment of inertia. The apparatus was previously developed for measuring the mechanical properties of the forearm by considering it as a single degree of freedom mechanical system described in Lin et al., 2001.

A Biodex™ (Shirley, NY) apparatus was used for isometric strength testing. The shoulder, forearm and wrist were positioned in a neutral position with the elbow flexed at 90°. Two forearm supinator isometric maximum voluntary contractions (MVC) of five-second duration were performed with a one minute rest between exertions.

Subjects were evaluated clinically for the presence of forearm swelling. Forearm circumference measurements were collected as a measure of edema in the muscles of the forearm prior to tool operation, immediately following and 24 h later. Circumference measurements were taken at a point 2.5 cm distal to the lateral epicondyle. The location was marked on the skin for reproducibility of measurement.

All subjects received a detailed explanation of the study prior to obtaining informed consent. The University of Wisconsin internal review board had approved the protocol and consent forms.

A mixed model repeated measures analysis of variance was used to investigate the significance of the main and interaction effects of peak torque and joint type on mechanical and physiologic measures over time. Logarithmic transformation of the variables was applied due to skewness in the distribution.

## RESULTS

Static forearm supination strength significantly decreased ( $F(2,14)=21.955$ ,  $p<.001$ ) following tool use (Table 1). The high peak torque (HPT) groups demonstrated the greatest decrease in isometric MVC with an average of a 15% decrease immediately following exercise. The low peak torque (LPT) groups demonstrated an average 10% decrease in isometric MVC. All groups except the HPT/short build up time (SBT) returned to within 6% of pre tool operation strength.

Table 1. Isometric Maximum Voluntary Contraction (Nm) Mean and SD

	High Peak Torque		Low Peak Torque	
	Long Build Up	Short Build Up	Long Build Up	Short Build Up
	n=7	n=8	n=7	n=7
Pre Tool Operation	10.57 (1.92)	11.53 (4.51)	9.50 (2.24)	10.60 (2.77)
Immediately Post Tool Operation	8.68 (2.09)	9.34 (4.17)	8.45 (2.54)	9.57 (2.67)
24 h Post Tool Operation	9.93 (2.63)	9.52 (4.01)	8.94 (2.97)	10.21 (2.52)

Mechanical properties of stiffness ( $F(2,50)=3.920$ ,  $p<.05$ ) and mass moment of inertia ( $F(2,50)=3.208$ ,  $p<.05$ ) were significantly affected by build up time. Mechanical stiffness changes are presented in Table 2. The LBT groups demonstrated the greatest decrease in stiffness (50% decrease for the HPT group and 35% decrease for the LPT group). The HPT/SBT demonstrated no change in stiffness immediately following exercise and the LPT/SBT group demonstrated a 22% increase in mechanical stiffness.

Table 2. Mechanical Stiffness (Nm) Mean and SD

	High Peak Torque		Low Peak Torque	
	Long Build Up	Short Build Up	Long Build Up	Short Build Up
	n=7	n=8	n=7	n=7
Pre Tool Operation	14.10 (4.83)	12.13 (11.85)	13.17 (8.76)	9.94 (4.98)
Immediately Post Tool Operation	6.99 (5.22)	12.16 (9.93)	8.55 (5.32)	13.10 (8.11)
24 h Post Tool Operation	15.10 (8.43)	11.69 (7.80)	11.02 (10.60)	11.42 (5.76)

Mass moment of inertia demonstrated similar changes as mechanical stiffness (Table 3). A decrease in mass moment of inertia was observed for the long build up time groups. The HPT/LBT group demonstrated a 70% decrease and the LPT/LBT group demonstrated a 50% decrease. Both the SBT groups demonstrated an increase in

mass moment of inertia, 66% for the HPT and 10% for the LPT group.

Table 3. Mass Moment of Inertia (kgm<sup>2</sup>) Mean and SD

	High Peak Torque		Low Peak Torque	
	Long Build Up	Short Build Up	Long Build Up	Short Build Up
	n=7	n=8	n=7	n=7
Pre Tool Operation	0.0076 (0.0062)	0.0065 (0.0116)	0.0124 (0.0099)	0.0055 (0.0071)
Immediately Post Tool Operation	0.0023 (0.0067)	0.0108 (0.0122)	0.0062 (0.0127)	0.0060 (0.0142)
24 h Post Tool Operation	0.0107 (0.0114)	0.0077 (0.0070)	0.0082 (0.0132)	0.0081 (0.0073)

The damping ratio magnitude was less than a 3% difference for all groups. Prior to power tool operation the overall average damping ratio was 0.039 (SD=0.023) and immediately following it was 0.040 (SD=0.020).

Forearm circumference increased following tool operation (F(2,24)=5.96, p<.05) but all groups demonstrated less than a 2% change in circumference.

Symptoms (using a 0-10 visual analog scale) increased following tool operation (F(2,24)=15.26, p<.001). All groups were asymptomatic at baseline. The LBT groups reported the greatest symptoms immediately following tool operation, 2.39 (SD=2.45) for the HPT group and 2.0 (SD=2.24) for the LPT groups. The SBT groups also reported symptoms but at a lower level, 1.14 (SD=1.38) for the HPT group and 0.64 (SD=1.40) for the LPT group.

The dynamic hand tool operator from Lin et al., (2001) was used to predict handle displacement and handle force for the pistol grip nutrunner that was operated on a vertical surface with a peak torque of either 3 Nm or 9 Nm, and either a short or long build up time. It is interesting to note that the two groups with the high handle force and displacement demonstrated the greatest change in mechanical stiffness (Figure 1) and mass moment of inertia following tool activity (Figure 2).

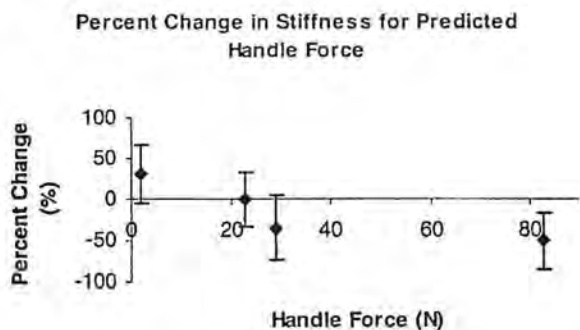


Figure 1. Percent change in stiffness for predicted handle force (N) (mean and SD)

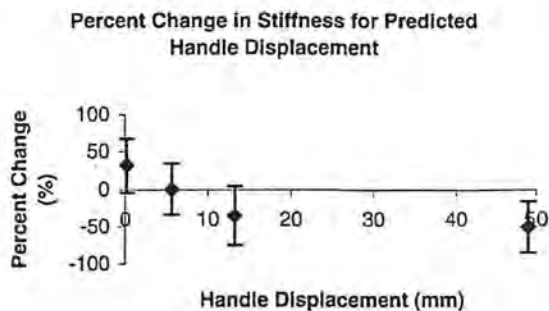


Figure 2 Percent change in stiffness for predicted handle displacement (mm) (mean and SD)

### DISCUSSION

The purpose of this experiment was to study the relationship between repetitive eccentric exertions in power hand tool operation and upper limb mechanical properties including stiffness, viscous damping and inertial mass, and physiologic measures including localized pain, discomfort, and swelling. Tool parameters of peak torque and torque build up time were controlled.

The present study demonstrated that for a small group of inexperienced power tool operators, an average decrease in stiffness (48%) and mass moment of inertia (60%) was observed immediately following pistol grip nutrunner operation for a long torque build-up time (250 ms) for both high peak torque (9 Nm) and low peak torque (3 Nm) tools. Sesto (2002) reported similar findings in symptomatic industrial workers, who demonstrated a decrease in mechanical stiffness (46%) and a decrease in mass moment of inertia (59%) as compared to asymptomatic industrial workers.

The change in damping ratio following power tool operation was less than 3%, which is considered insignificant in magnitude.

The high peak torque groups demonstrated the greatest decrease in isometric MVC with an average 15% decrease immediately following exercise. The low peak torque groups also demonstrated an average 10% decrease in isometric MVC.

In this study, isometric MVC and mechanical properties of stiffness and mass moment of inertia demonstrated recovery after 24 hrs. This was not observed in an earlier study (Sesto 2003) in which isometric MVC recovered after 72 hrs following moderate submaximal exertion but mechanical properties of stiffness and mass moment of inertia did not recover in the same time frame.

A limitation of this study is that subjects were inexperienced tool users. It is not known if similar mechanical differences are observed in experienced tool users operating tools with varying parameters in an occupational setting. The majority of subjects demonstrated recovery in strength and mechanical properties by 24 h after tool use, which indicates that the decrease in strength and

mechanical properties was only short term, although, this may be due in part to the subjects operating a power tool for a short duration (60 minutes).

### CONCLUSIONS

The magnitude of change in mechanical properties was observed in the forearm of inexperienced power tool users following short duration tool operation. An average decrease in stiffness (48%) and mass moment of inertia (60%) was observed immediately following pistol grip nutrunner operation for a long torque build-up time (250 ms) for both high peak torque (9 Nm) and low peak torque (3 Nm) tools.

The groups with the greatest handle forces and displacements demonstrated the largest decrease in mechanical stiffness immediately after tool use but recovery was observed at 24 hrs.

### ACKNOWLEDGEMENTS

This research was partially supported by a Grant from the University of Michigan Center for Occupational Health and Safety Engineering and the National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention.

### REFERENCES

- Armstrong, T., Bir, C., Foulek, J., Martin, B., Finsen, L. and Sjogaard, G. (1999). Muscle responses to simulated torque reactions of hand-held power tools. *Ergonomics* 42(1): 146-159.
- Leger, A. B. and Milner, T.E. (2000). Passive and active wrist joint stiffness following eccentric exercise. *Eur J Appl Physiol*, 82, 472-479.
- Lin, J. L., Radwin, R.G. and Richard, T.G. (2001). Dynamic biomechanical model of the hand and arm in pistol grip power handtool usage. *Ergonomics* 44(3), 295-312.
- Oh, S. A. and Radwin, R.G. and Fronczak, F.J. (1997). A Dynamic Mechanical Model for Hand Force in Right Angle Nutrunner Operation. *Human Factors*, 39(3), 497-506.
- Oh, S. A. and Radwin, R.G. (1998). The Influence of target torque build up time on physical stress in right angle nutrunner operation. *Ergonomics*, 41(2), 188-206.
- Sesto (2002). Biomechanical and physiological changes following submaximal eccentric activity. Doctoral dissertation, University of Wisconsin
- VanBergeijk, E. (1987). Selection of power tools and mechanical assists for control of occupational hand and wrist injuries. In ACGIH (Ed.) *Ergonomic Interventions to Prevent Musculoskeletal Injuries in Industry*. Chelsea, MI.: Lewis Publishers.
- Warren, G. L., Hayes, D.A., Lowe, D.A., Prior, B.M. and Armstrong, R.B. (1993). Materials fatigue initiates eccentric contraction induced injury in rat soleus. *Journal of Physiology*, 464: 477-489.