Dynamic Power Tool Operation Model: Experienced Users vs. Novice Users

Jia-Hua Lin, Raymond W. McGorry, and Chien-Chi Chang

Liberty Mutual Research Institute for Safety
Hopkinton, MA, USA
Jia-hua.lin@libertymutual.com

Abstract. Previous study demonstrated that a single-degree-of-freedom mechanical model can represent a human power tool operator subjective to impulsive torque reactions. Using only novice tool users, it was shown that the mechanical capabilities to respond to tool torque reaction depended on workstation location and orientation, and varied among users (Lin, Radwin, & Richard, 2000). It was hypothesized that the mechanical model elements among experienced tool operators may be different from novice users. A laboratory study was carried out to measure the equivalent mechanical parameters among the novice and experienced tools users. The results demonstrate the difference between the two groups. Those may represent the strategy developed by the experienced users to minimize the impacts from the impulsive torque reactions.

1 Introduction

Human limbs have been modeled as a single-degree-of-freedom mechanical system to understand their dynamic characteristics (Aruin & Zatsiorsky, 1984; Hunter & Kearney, 1982; Lakie, Walsh, & Wright, 1980; Reynolds & Soedel, 1972; Zawadzki & Kornecki, 1988). Tool operators have also been modeled as equivalent mechanical systems (Hansson & Kihlberg, 1983; Lin, Radwin, & Richard, 2001; Lindqvist, 1993) to understand the effect of powered hand tool torque reaction of the hand-arm system. The operator can be represented using a single-degree-of-freedom system, which consists of a spring, an inertial mass, and a damping element. The mechanical elements can be identified by observing the response when the hand-arm is subject to a viscoelastic loading (Lacquaniti, Licata, & Soechting, 1982; Lin et al., 2001). The mechanical elements were found to be affected by work locations (Lin et al., 2001) and postures (Hogan, 1990).

Experience was identified as a factor influencing hand tool performance because of different techniques used between experienced and novice users (Rockwell & Marras, 1986). Kearney and Hunter (1990) pointed out that the substantial inter-subject variability in joint dynamics suggests the data measured for one population may limit its application for another. Therefore, this project aimed to identify if operator

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experience affected the hand-arm equivalent mechanical system responding to the impulsive torque reactions encountered in common power tool operations.

2 Methods

To identify the hand-arm equivalent mechanical parameters, an oscillating elastic loading test battery was constructed. The principle of the battery was that when the hand gripped the attached handle, the mechanical system of the operator (consisting of equivalent mass, spring and damping elements) was added to that of the battery. It resulted in a new mechanical system of different impulse response characteristics. By measuring the response characteristics, the operator system could be identified. The battery consisted of a mass coupled with a spring. Through the center of the mass was a spindle, whose end was connected to a handle for the operator to grasp. The handle, which simulates pistol grip or right angle handle shapes, could measure hand force and spindle torque. A solenoid switch was mounted on the battery, controlled by the trigger installed at the handle, to release the mass and start the oscillation for a trial.

Thirty right-handed male participants, free of musculoskeletal disorders, were recruited and gave informed consent to participate in this study approved by our institutional review board. Participants were considered experienced tool users if they had at least one full year in any previous or current job where using power hand tools such as screwdrivers, nutrunners, or wrenches was necessary and part of the job.

There were 27 trials (3 oscillating frequencies × 3 horizontal distances × 3 vertical distances) for each participant. For each trial, the participant was asked to grip the handle on the test battery in the same manner as holding a corresponding tool. When ready, the trigger was pressed by the participant, the handle should be stabilized around its neutral position. Each oscillation lasted less than 3 seconds. The mechanical elements measured on the pistol grip handle on the vertical surface are reported in this paper.

3 Results and Discussion

The results demonstrate that operator hand-arm stiffness was significantly affected by vertical ($p < 0.001$) and horizontal ($p = 0.001$) locations. The trends in Figures 1 and 2 show that as the horizontal distance between the handle and the operator increased, and as the handle height was lowered, hand-arm stiffness decreased. This was consistent with the previous findings (Lin et al. 2003). Experienced tool users exercised less, although not statistically significant, stiffness to react against the tool handle than novice users (Figure 1).

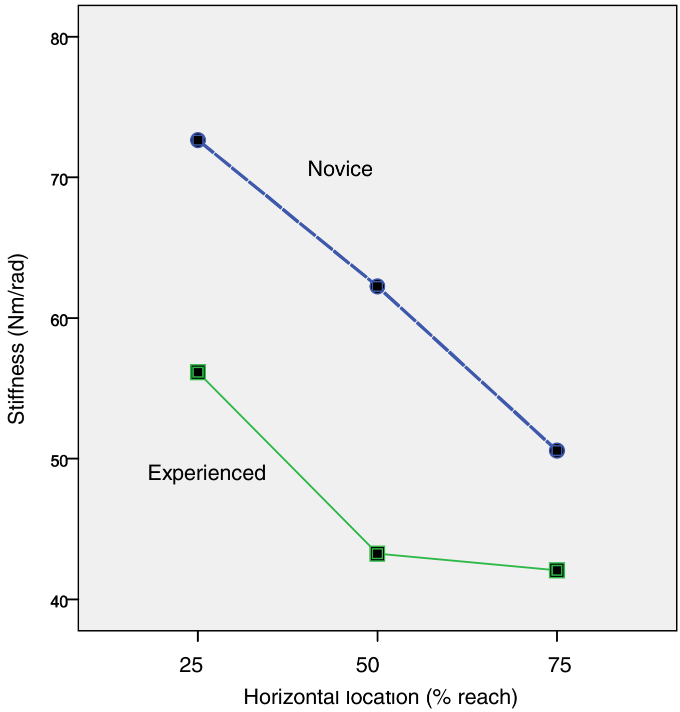

Fig. 1. Average operator hand-arm stiffness by experience and horizontal location

The equivalent inertial mass the operator posed to the tool handle was significantly affected by experience ($p= 0.008$), horizontal ($p< 0.001$) and vertical ($p= 0.001$) locations. The means of the operator inertial mass by each study level are listed in Table 1. The damping element was not affected by any study factors, although experienced operators had greater coefficients (1.9 N·sec/m) than the novice operators (1.2 N·sec/m).

Stiffness and inertial mass are the two elements having the greatest influences in the model that describes and predicts operator hand-arm dynamics (Lin et al. 2003). Based on the single-degree-of-freedom model, the greater the stiffness and the inertial mass, the less the hand displacement. From the current findings, experienced operators produced a greater inertial mass but less stiffness while counteracting the impulsive disturbance similar to those encountered in power tool use. Lin et al. (2007) observed that while exposing to different tasks, which resulted in different level of torque exposure, experienced tool users allowed consistent handle displacement while novice users were highly affected by the torque exposure level. Novice users allowed a significantly greater handle motion to a soft joint than a hard joint. Further, in both exposures, experienced users allowed less displacement. The current findings support that experienced users may alter their equivalent mechanical properties to accommodate various torque exposure to minimize discomfort or physical disturbances.

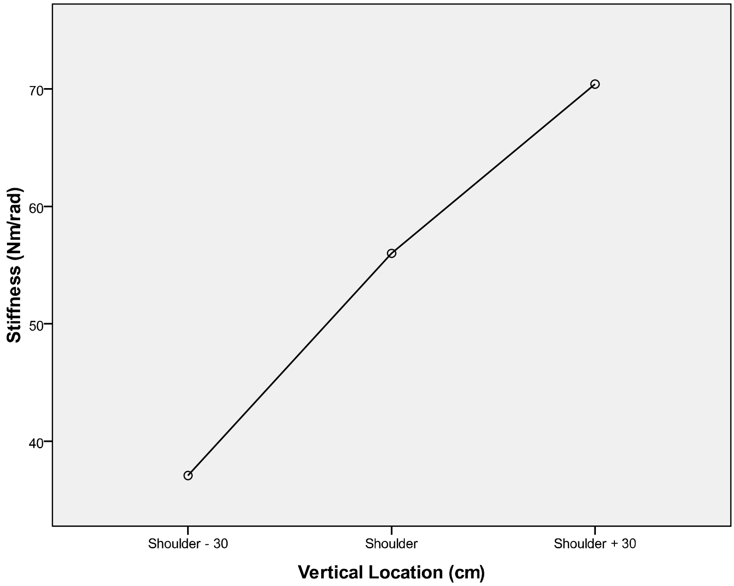

Fig. 2. Average operator hand-arm stiffness by vertical location

Table 1. Average operator hand-arm inertial mass by experience, vertical, and horizontal location

Factor	Level	Inertial mass (Nm s^2)
Experience	Novice	.019
	Experienced	.031
Vertical location	Shoulder - 30	.021
(cm)	Shoulder	.020
	Shoulder + 30	.034
Horizontal location	25	.019
(% reach)	50	.019
	75	.036

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