

PREDICTING EXPOSURE OF FINGER FLEXOR MUSCLES AND TENDONS TO DYNAMIC LOADS DURING FINGER TAPPING

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INTRODUCTION:

Exposure to different key switch designs within a computer keyboard has been associated with different levels of Carpal Tunnel Syndrome symptoms (Rempel et al., 1999). However, knowledge of the associated forces within the tendons that traverse the carpal tunnel remains limited. Biomechanical models predicting exposure often assume quasi-static equilibrium and neglect the dynamics of the finger mass (Buchner, 1988). Our goal was to use a lumped parameter dynamic model of the finger, predicting effective values for tendon forces during finger tapping to evaluate different motor control conditions.

METHODS

Ten healthy people (5 f, 5 m, 25-36 yrs) participated in the study, which was approved by the IRB Committee. Participants tapped repeatedly on a flat plate with their right index finger while the fingertip contact force and movement were measured simultaneously. A single-camera motion analysis system tracked the vertical position an infrared LED glued to the fingernail (Resolution = 0.040 mm). A strain gauge based force sensor mounted beneath the flat plate measured the fingertip force (rms noise = 3mN).

The finger was modeled as a linear second order mass-dashpot system (Hajian et al., 1997). The parameters for the dynamic model were only calculated for the first 40 ms of fingertip contact and therefore the effective muscle force was assumed to be proportion to time after the initiation of the fingertip contact with an initial level of force. Simple least squares regression techniques estimated the parameters for the model for each tap.

Four different tapping conditions tested the model robustness across motor control conditions. First, the hand and finger during the tapping task were relaxed with all five digits extended and in a natural orientation. Second, subjects curled digits three, four and five under the palm and squeezed with a moderate to high amount of effort creating a co-contraction. Third, subjects repeated the relax condition, but with an increased downward velocity of the fingertip prior to impact. Fourth, the co-contraction task was also repeated with an increased fingertip velocity. Subjects were instructed to minimize the contact time with the force sensor. Data were collected on a PC at 10kHz for thirty taps. Parameters were averaged across taps and each subject and then averaged across the subjects within each condition.

RESULTS and DISCUSSION

Most of the dynamic activity occurred within the first 10 milliseconds with the inertia (acceleration) and damping (velocity) forces quickly approaching zero (Fig. 1). The effective muscle force contributes most of the force thereafter. The mass and damper parameters varied little over the four conditions tested and are consistent with Hajian et al. (1997). The effective muscle force, however, did vary considerably over the four conditions (Table 1). The rate of change in force increased significantly during the co-contraction of other hand muscles through the making of a partial fist. The initial muscle force increased with the speed of the tap down-stroke suggesting extra muscle effort was used to accelerate the finger during the faster taps.

The model had relatively small errors with root mean square errors (RMSE) of 0.3 N and the variance of the measured force accounted for (VAF) averaged 93%. A large portion of the error occurred during the impact phase of the force trajectory. The inertia force diminished before the impact force began to decrease. This error was attributed to by the energy absorption of the interphalangeal (IP) joints increasing the duration of the impact. Measuring the IP

joint angles during a keystroke would reduce such a mechanism.

The results suggest that the lumped parameter model can be used to examine differences of effective muscle loads between motor control scenarios. The limitations of the model require future work investigating the specific IP kinematics during the impact phase of the key strike.

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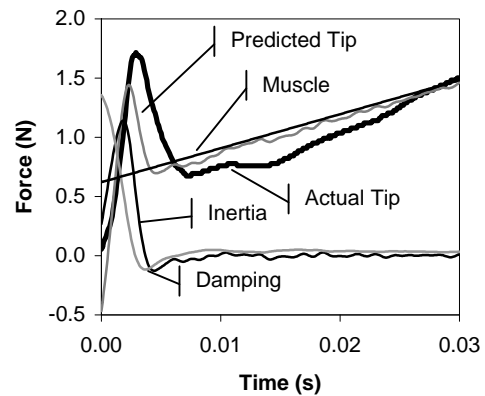


Fig. 1: Tip and model predicted force trajectories for a typical tap

REFERENCES:

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 Hajian et al. *J Biomh-Eng* 1997; 119(1):109-14.
 Rempel et al. *JOEM* 1999; 41(2): 111-9.

Table 1 Lumped parameter model estimates -- mean values and (standard deviation).

Parameter	Relaxed	Relaxed fast	Fist	Fist fast
Mass (g)	6.0 (0.6)	5.2 (0.4)	5.5 (0.7)	5.2 (0.6)
Damper (N/m/s)	1.9 (0.1)	2.3 (0.2)	2.0 (0.2)	2.4 (0.3)
Initial Force (N)	0.9 (0.2)	1.6 (0.3)	0.9 (0.3)	1.5 (0.3)
Force Rate (N/s)	-0.9 (6.3)	-10.8 (8.2)	34.7 (13.9)	47.9 (20.7)
RMSE (N)	0.3 (0.1)	0.4 (0.1)	0.2 (0.1)	0.4 (0.1)
VAF (%)	91 (1)	92 (2)	94 (1)	93 (2)