FINGERTIP PULP MECHANICS DURING VOLUNTARY TAPPING

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INTRODUCTION

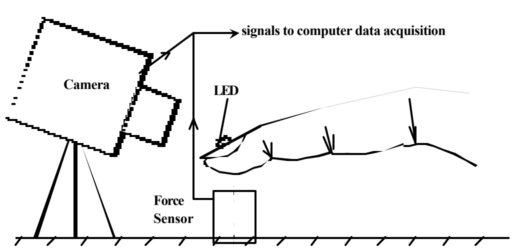
Increased use of computer keyboards is associated with increased incidence of musculo-skeletal disorders (MSDs) of the upper extremity. Epidemiology studies indicate that one possible risk factor for the development of MSDs is the mechanical load to the soft tissues. To understand and predict the mechanical load on the soft tissues of the hand and arm during tapping activities, we seek to build a lumped parameter model of the finger, hand and wrist. We first chose to characterize the mechanics of the fingertip pulp during tapping because forces at the fingertip must be transmitted to more proximal segments through the fingertip pulp.

The mechanics of the fingertip pulp has been modeled during static and dynamic loading using sinusoidal and ramp inputs (Pawluk and Howe, 1999; Serina *et al.*, 1997). However, tapping movements contain high-frequency components that may not be well characterized by existing models (Pawluk and Howe, 1999). We therefore conducted experiments to determine whether a simple model of the fingertip pulp adequately describes its mechanical behavior during dynamic tapping tasks similar to those experienced during typing.

MATERIALS & METHODS

We measured vertical force at the fingertip using a stiff force sensor, and position of the fingertip using an optical measurement system and a light-emitting diode glued to the fingernail (Figure 1). Eight subjects tapped on the force sensor while fingertip position was measured. Subjects were instructed to minimize contact time for each tap and tap once per second. Position signals were filtered and differentiated to yield velocity and acceleration.

Figure 1. Experimental apparatus used to measure tap mechanics.



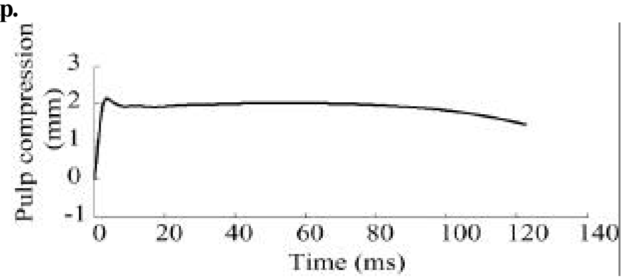
A simple dynamic model was fit to the resulting force and position data. Following Pawluk (1999), functions for the instantaneous elasticity $T^{(e)}(x)$ and relaxation $G(t)$ were used to characterize the behavior of the fingertip pulp.

Force caused by instantaneous elasticity was modeled as an exponential function of position $T^{(e)}(x) = \frac{b}{m}\left[e^{mx} - 1\right]$, and force change due to relaxation was modeled as an exponential function of time $G(t) = c_0 + c_1 e^{-vt}$.

RESULTS

When subjects were instructed to tap on the force sensor in a comfortable manner, with the rest of the hand relaxed, the fingertip pulp was rapidly compressed during the first 10 ms of the tap, then maintained relatively constant amount of compression (Figure 2).

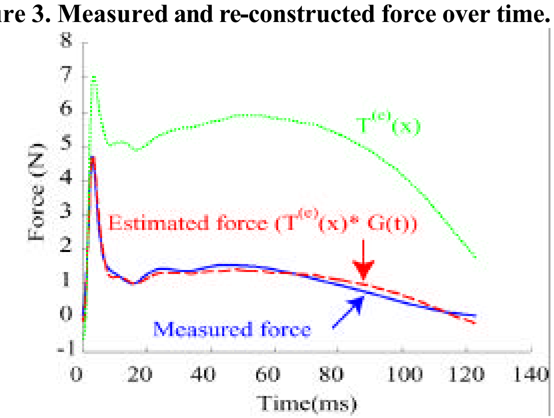
Figure 2. Pulp compression over time for a representative tap.



Force production was characterized by an initial force peak, corresponding to the compression of the fingertip, followed by a decrease in force caused by rapid relaxation of the fingertip pulp (Figure 3).

A simple model of fingertip pulp mechanics exhibiting instantaneous elasticity and rapid relaxation was able to re-construct the mechanical behavior of the fingertip pulp to root-mean-squared errors of 10% (Figure 3). These errors are similar to the 4-10% errors achieved for simpler inputs (Pawluk and Howe, 1999).

Figure 3. Measured and re-constructed force over time.



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