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Measuring pad–pad pinch strength in a non-human primate: *Macaca fascicularis*

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Abstract

The primary purpose of this study was to establish a methodology for determining and perhaps predicting (via regression analysis of anthropometric measures) *Macaca fascicularis* isometric pinch strength for a specific task. The larger purpose of this work was to properly scale a pinching task for the monkeys in order to study dose-response relationships in a non-human primate model for carpal tunnel syndrome. Three female and one male macaque ($n = 4$) of varying size and age were trained to perform a left-handed pad–pad pinch. The task required 60° of wrist flexion at a static pinching distance of 3 cm between the thumb and fingers. Subjects were trained for a period of 20-weeks. After that time, an analysis of performance gradients found that they had each reached a plateau in their force output. Pinch strength for the four animals ranged from 29.4 to 59.8 N. Regression analysis revealed that body mass (kg) and wrist circumference (cm) were both predictive of pinch strength, exhibiting adjusted R^2 values of 0.93 ($p = 0.024$) and 0.96 ($p = 0.015$), respectively. Thus, the results suggest that maximal pinch strength could be acceptably estimated in future subjects using either the wrist circumference or the body mass measures, as both were strong predictors of pad–pad pinch strength.

Keywords: Primate; Pinch strength; Carpal tunnel syndrome; *Macaca fascicularis*

1. Introduction

Previously developed human and animal models have shown the relationship between hand use and nerve function measures associated with the development of Carpal Tunnel Syndrome (CTS) (Armstrong and Chaffin, 1979; Bernard, 1997; Clark et al., 2004). It has been demonstrated that risk for CTS increases with the amount of force exerted (Armstrong and Chaffin, 1979; Chiang et al., 1993; Silverstein et al., 1987; Smith et al., 1977). Physiologically, forceful pinching exertions are considered hazardous because they increase the compartment pressure within the carpal tunnel, imposing stress on the median nerve (Cobb et al., 1996; Keir et al., 1998). However, it is difficult for epidemiological studies to analyze this multifactorial disease to the point where a dose-response relationship between exerted forces and the onset of CTS can be described (Loslever and Ranaivosoa, 1993; Viikari-Juntura and Silverstein, 1999). An animal model is required to directly address their causal relationships.

Our long-term research goal is to study the link between task force requirements and the onset of CTS in humans using an animal (*Macaca fascicularis*) model. The model design requires the execution of a controlled task with a left-handed pad–pad pinch. However, in order to appropriately scale the task in the CTS model, we first need to quantify the strength capacity of the animals as they perform the

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designated task. Unlike human subjects, neither hand strength data (Mathiowetz, 1985) nor established techniques (Kroemer and Marras, 1981) exist for determining primate hand strength. The literature offers only theoretical calculations (Graham and Scott, 2003) or crude experimental designs (Preston et al., 1970) to address these questions.

Therefore, the primary objective of this study was to develop a methodology for determining the maximal static voluntary exertion for normal healthy *M. fascicularis* monkeys using a specific hand and wrist posture combination. A secondary aim was to determine if selected anthropometric parameters could be used to predict the strength of future subjects on the same task.

2. Methods

2.1. Subjects

Four *M. fascicularis* monkeys were used. Subject care followed the NIH Guide for the Care and Use of Laboratory Animals and an approved ILACUC protocol of The Ohio State University. The subjects' physical attributes are provided in Table 1. Before the experiment was initiated all animals were trained to sit in a primate chair. The animals were food deprived on training days (5 days per week) in order to motivate them to earn their rations by working at the task. Body mass was monitored weekly to insure proper nutrition (no animal lost more than 20% of original body mass throughout the study).

2.2. Anthropometry

Following the 20-week testing period, readily producible and relevant distal upper extremity anthropometric measurements were recorded for use in a possible predictive regression analysis. Age was estimated from animal records. All other measurements were acquired while the animal was maintained under general anesthesia via inhaled Isoflorane (1–2%); ketamine hydrochloride (13 mg/kg i.m.) was used as a preanesthetic. Body length was determined by placing a board at the feet of the animal while lying supine. Hand length, hand breadth, and elbow-fingertip length were obtained as defined by Kroemer (1999). Wrist circumference was measured at the wrist, immediately proximal to the pisiform and the macaques unique "hypothenar callus". Forearm length was calculated by subtracting the hand length from the elbow-fingertip length. Forearm circumference was obtained by finding the maximal circumference about the forearm.

2.3. Apparatus

The chair-trained animals were placed in a testing booth equipped with a closed circuit camera. Positioned in front of the animal was a custom built isometric pinching apparatus comprised of two machined aluminum "tongs" sandwiching a commercial force sensor [Model 6010: Foil-Gauge, Planar-Beam Stainless Steel Force Sensor (Advanced Custom Sensors, Inc.®)]. The 3 cm pinch distance between the grasping surfaces of the tongs was consistent across subjects. The pinching apparatus was mounted vertically on a piece of 0.6 cm clear polycarbonate at a 60° offset from the hand entrance, which was constructed from a 7.6 cm length of 3.2 cm diameter PVC tubing (Fig. 1). To insure the animal's safety from wiring and avoid tampering, another piece of 0.6 cm clear polycarbonate shield was placed between the monkey and the back of the device. Therefore, the only access to the device was through the allotted hand entrance. The device was constructed to eliminate the possibility of one-sided pulling/pushing. Positioning of the device was controlled to insure proper pinching and prevent rewards for inappropriate exertions. An auditory sustained buzzing was supplied to let the animal know when a pinch was no longer being performed correctly and would not be reinforced.

Labview virtual instrument software (National Instruments Corporation, Austin, TX, USA) was used for data collection, control of the food pellet dispenser and visual/auditory feedback. The program recorded the peak voltage from each exertion along with the corresponding reinforcement threshold in effect during the exertion.

Prior to training, and periodically throughout the course of the study, the device was calibrated to insure a proper linear voltage-to-force relationship and to determine the amount of mechanical advantage the "tongs" provided against the force gauge. Calibration was accomplished by utilizing a conventional digital force gauge with a range of 0–44.0 N (Wagner Instruments® Model FDV 100). The force gauge was used to push one side of the device while the other was held in place by a clamp. The relationship between the peak compression force and the recorded peak voltage was linear (adjusted R-squared of 0.98). Real-time visual feedback was provided to the subjects through an analog display of the force being exerted and the target level of force required for reinforcement.

Table 1
Demographics, anthropometrics, results from pinch force testing and regression analysis for the four animals studied

Subject	1	2	3	4	Adj[a] R^2	p-Value[a]
Gender	Male	Female	Female	Female		
Pinch strength	59.8	43.2	29.4	34.3		
Wrist circumference (cm)	8.3	7.1	6.4	6.9	0.95	0.02
Forearm length (cm)	14.7	12.8	12.1	12.1	0.94	0.02
Mass (kg)	5.1	4.2	3.6	4.1	0.93	0.03
Hand breadth (cm)	4.0	3.3	3.3	3.3	0.73	0.10
Hand length (cm)	9.3	8.0	8.0	7.8	0.73	0.09
Forearm circumference (cm)	12.1	11.1	10.0	9.7	0.86	0.05
Age (years)	4.5	7.0	15.5	22.5	0.46	0.20
Height (cm)	74.8	64.3	67.0	64.5	0.43	0.21

All extremity dimensions are from the left limb.
[a] Results from a regression analysis compared with pinch strength.