Design and Fabrication of a Device for Studying Unstable Grasp Mechanics

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Abstract:
Fingertip forces during static grasp exhibit rich stochastic dynamics. Here we present a device that was designed and fabricated in order to extend dynamical studies of grasp and uncover underlying neuromuscular mechanisms. Previous experiments have used a device that locks three force sensors (one each for the thumb, index, and middle fingers) into a fixed position and a weight is attached to the bottom of the device. The new device can also be locked, but can additionally be released so that the sensors are free to pivot about the center. This device enables studies that involve perturbation of an inherently unstable static grasp.

Introduction:
The study of isometric force production as well as static grasp has revealed signal-dependent noise present at the muscle level [1,2]. However, closer inspection of load-cell data during static grasp reveals that SDN may not explain all of the complex, stochastic fluctuations of fingertip force generated by the 8 muscles of the thumb, 7 muscles of the index finger, and 6 muscles of the middle finger [1].

This aforementioned static grasp study utilized the device shown in Figure 1. The 3 arms pictured were locked into the most comfortable position for the subject before the data collection began. Weights between 50 and 250 grams were attached to the bottom of the device, and the device was held in a static position for a certain amount of time while force data from the load cells as well as Vicon® motion data from the device were collected.

Figure 1: Previous device.

There were several limitations of the previous design of the device. One was that it was unadjustable for different sized hands. This is particularly problematic when trying to compare the static grasp characteristics of children with those of adults. A second drawback was that the weight was hanging from the bottom of the device, leading to "pendulum-like" dynamical effects that were present during the noisy micro-motion of the device. Furthermore, the load cells could only be locked into place and had no way to freely rotate about the center, which prohibited the study of unstable grasp as well as the effects of unexpected perturbations.

This new device eliminates all of these problems to allow for more comprehensive and flexible studies. To summarize, the new design requirements were:

1. Center of mass in the center of the load cells
2. Ability for load cell arms to freely pivot about the center of the device with little or no friction
3. Adjustability for different hand sizes

Methods:
The device was initially designed in SolidWorks®. The material properties were input into the 3D model to allow for calculation of the center of mass. The design was drawn up keeping in mind ease of machining, durability, repairability, availability of materials, and fulfillment of the design requirements. The final 3D drawing of the device is shown in Figure 2.

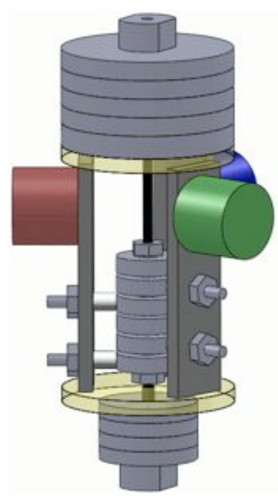

Figure 2: SolidWorks drawing of new device.

Brass was used for the weights on the top and bottom, and they could be attached or removed in order to add 50, 100, 150, 200, and 250 grams to the base mass of the device while still keeping the center of mass in the center of the load cells.

This fulfilled design requirement #1. The weights were fabricated using a 3-axis CNC machine.

ABEC-5 stainless steel ball bearings were press-fit into a fabricated aluminum "washer" which allowed the attachment of the load cell arms to the ball bearings which could freely pivot around the threaded center rod, as shown in Figure 3. This fulfilled design requirement #2. Aluminum plates at the top and bottom of the arms can be compressed down upon the arms in order to lock the arms in place as needed.

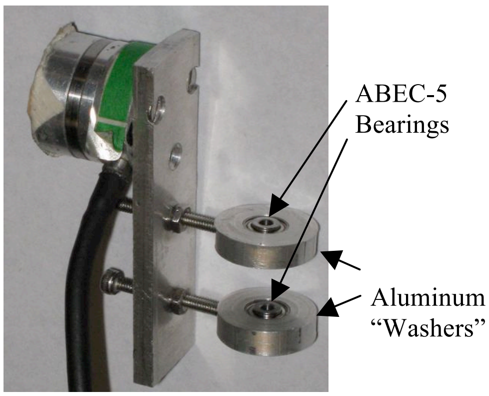

Figure 3: The design of a single arm.

The arms were mounted on screws protruding from the center to allow the arms to be adjusted in or out by adjusting the securing nuts to the appropriate position on the screw, also shown in Figure 3. This fulfilled design requirement #3.

The final device is shown in Figure 4.

Figure 4: Final fabricated device with load cells attached.

Discussion:

The fabricated device was well-centered and the arms could rotate with little or no friction when free. It was also easy to lock the arms in place if desired. The arms are continuously adjustable so that all hand sizes can be appropriately studied.

This device may uncover neuromuscular mechanisms of dynamic grasp because it will present the nervous system with a much more difficult task for the nervous system to accomplish when the arms are freely pivoting. This can be seen in Figure 5. In addition to the requirement that the sum of forces and moments on the device must be equal to zero, the forces must be directed exactly at the center, otherwise the arm will pivot to one side or the other.

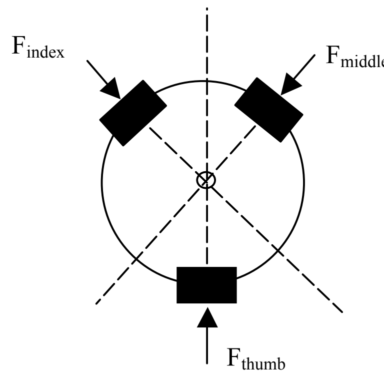

Figure 5: Forces applied with new device must be directed exactly at the center of rotation.

Future experiments will determine if this newly-fabricated device has sufficiently complex dynamics to uncover new modes of nervous system function at the muscular or cortical level.

References:

[1] Rácz, K., and Valero-Cuevas, F., 2009. "The grip force dynamics of static grasp reveals a control hierarchy". *Proceedings of the Nineteenth Annual Meeting of the Society for the Neural Control of Movement.*

[2] Jones, K., Hamilton, A., and Wolpert, D., 2002. "Sources of signal-dependent noise during isometric force production". *Journal of Neurophysiology.* **88**(3). p. 1553.

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