A Theoretical Study of the Effect of Elbow Muscle Co-Contraction Level on Forearm Steadiness

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INTRODUCTION
Some older adults struggle to perform everyday tasks requiring fine motor skills. These include precise movements such as buttoning shirts, tying shoes, feeding themselves, using phones, or inserting a key in a lock. The performance of many of these tasks is frustrated by a lack of hand steadiness. The literature suggests that older adults have less hand steadiness than younger adults [1] as well as higher amounts of co-contraction [2].

Upper extremity steadiness has been quantified as the variation in hand position both for static tasks [2] and for reaching tasks [3]. Increased co-contraction is associated with lower inter-movement trajectory variability within same subjects [4]. No association was found between co-contraction and acceleration variability between subjects [2]. However, the effect of co-contraction on within-subject positional variability within a given single movement or task, which is closely related to steadiness, has not been studied.

The goal of this research, therefore, was to determine if the additional co-contraction exhibited by older adults is a compensatory action to steady the hand or if it is a source of additional positional variability. Our working hypothesis is that, in the healthy individual, elbow muscle co-contraction level largely determines the steadiness of the forearm. Our primary hypothesis is that there exists an optimum co-contraction level that maximizes forearm steadiness. The secondary hypothesis is that an age-related decrease in muscle contractile strength leads to decreased optimal steadiness.

METHODS
We developed a planar model of the upper and lower arm complete with four major agonist and four major antagonist muscles of the elbow (Figure 1). The moment and stiffness developed by each muscle was considered a function of muscle cross-sectional area, moment arm, and activation level. The muscles develop a net moment about the joint, along with a rotational resistance to internal or external perturbing moments that is based upon the short range muscle resistance to stretch (but not compression, of course). We assumed the normal variability (SD) in the magnitude of each muscle force to be a function of muscle cross-sectional area and activation level [5]. The variation in each muscle force contributes to variability in the net joint moment as well as net joint stiffness. The stiffness was then used to calculate the positional variability of the forearm, assuming the upper arm was grounded.

Given the external moment applied to the joint and the co-contraction level of the muscles, a MATLAB algorithm solved for the muscle activation pattern that minimizes the positional variability of the elbow. The co-contraction level was then varied to determine the effect of co-contraction on forearm steadiness and test the primary hypothesis.

We next varied the muscle properties of the model muscles to simulate how these might affect the steadiness of the forearm in younger and older adults. The simulation was then used to find the optimum co-contraction level that maximized the steadiness of the hand for both the younger adult model and the older adult model. The secondary hypothesis was then tested.

Figure 1: Simple Elbow Joint Model
RESULTS AND DISCUSSION
The simulation results demonstrated an optimum co-contraction level that maximizes forearm steadiness supporting the primary hypothesis (Figure 2). Higher levels of co-contraction were associated with more variability. This finding is contrary to studies which examined the variability between movements and then applied the same reasoning to a single movement [3,4].

The simulation results suggest that people with weaker muscles, such as many older adults, will show a decrease in steadiness supporting the secondary hypothesis (Figure 3). This corroborates findings of manual steadiness in older subjects [1]. While muscle strength is not the only change that occurs with age, the model was sufficiently sensitive to this parameter to replicate the aging effect on steadiness.

The simulation also suggests that older adults have lower optimal co-contraction levels when exerting the same external moment as younger adults. This result suggests that the higher level of co-contraction seen in older adults is not to increase steadiness. Since co-contraction decreases the effect of internal or external disturbances, the elderly may be favoring joint stiffness over steadiness. If these modeling predictions were to be validated by experiment, then future interventions might target co-contraction levels in older adults.

CONCLUSIONS
The results suggest that elbow muscle co-contraction level plays a significant role in forearm steadiness. Positional variability is predicted to be increased at the greatest co-contraction levels which is contrary to current dogma. The simulation also predicts reduced steadiness in older adults based solely on the decrease in muscle cross-sectional area associated with aging.

REFERENCES

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