A comparison of shear wave elastography and PID controllers for *in-silico* muscle activation modeling

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Summary

The majority of fighter pilots experience neck pain from their helmets, and a noninvasive technique to study the loads on pilots' spines are cervical spine finite element models. To have physiologically relevant results, muscle forces must be accurate. This study compares PID controllers and shear wave elastography (SWE) as methods for estimating muscle forces. The results suggest that SWE may provide more physiologically meaningful muscle forces than PIDs.

Introduction

97% of fighter pilots report experiencing neck pain [1] as a result of their helmets [2]. However, the mechanism of pain is unknown, and is likely due to muscle and nerve dysfunction. It is difficult to noninvasively study these factors *in-vivo*, so this study utilizes finite element models (FEMs) to understand the impact of helmet loads on muscles in the cervical spine. PID controllers have often been used in neck models to estimate muscle forces in car crash scenarios [3]. Additionally, shear wave elastography (SWE) has been proposed as a method to estimate individual muscle forces [4], but these forces have never been implemented into a FEM.

This study compares PID controllers and SWE as methods for muscle activation in a cervical spine FEM. The distribution of muscle forces required stabilize the spine with and without helmet loads will provide insight into the pain generating strains put on fighter pilots' necks.

Methods

The validated VIVA OpenHBM cervical spine FEM [5] was modified to add gravity, and two conditions were tested: with helmet loads (H) and with no helmet (NH). In each condition two different methodologies, PID and SWE, were used to achieve muscle activations that would stabilize the head.

PID controllers assign coefficients to each muscle to activate to oppose rotation of the head from its neutral position. SWE can measure the shear modulus of individual muscles, and the activation of each muscle can be calculated from these values. The activation of the trapezius, semispinalis capitis, semispinalis cervicis, splenius capitis, and multifidus were measured on a participant with and without a helmet on, and the remaining muscles used a PID controller. Total muscle force and distribution of forces was analyzed and reported for all muscles, extensors only, flexors only, and muscles measured with SWE.

Results and Discussion

The total muscle force in the NH and H conditions was similar across the PID and SWE techniques (Table 1). However, there were significant differences between the SWE NH and H conditions, and the increase in PID muscle forces were insignificant. The SWE muscle forces increase more uniformly across all muscles, while the PID muscle forces largely remained the same except for a large increase in force produced by the trapezius. When separating into flexor and extensor contributions, the PID controller underestimated extensor NH forces and overestimated extensor H forces.

Table 1: PID vs. SWE muscle force results and distribution. All muscle forces, extensor, and measured muscle contributions were significantly different from NH to H (*p < 0.05).

	PID		SWE	
	No helmet	Helmet	No helmet	Helmet
All muscles total force (N)	148.8	165.6	142.4	171.0*
Extensor contribution (%)	59.9	84.6	66.6	75.3*
Flexor contribution (%)	40.1	15.4	33.4	24.7
Measured muscle contribution (%)	19.9	48.8	22.9	32.8*

The PID muscle forces increased by 16.8N from NH to H with the largest increase being 15.2N (339%) in the trapezius. The SWE muscle forces increased by 28.6N from NH to H with the largest increases being 3.9N (141%) in semispinalis cervicis and 1.8N (267%) in splenius capitis.

Incorporating SWE muscle activation into FEMs yielded a different muscle force distribution than PID controllers. While overall magnitude remained similar, PID controllers preferentially increased forces in larger muscles. Conversely, SWE potentially provided a more physiologically relevant force distribution, particularly in smaller stabilizing muscles. Relying solely on PID controllers in FEMs may misrepresent pain mechanisms by suggesting excessive strain in larger muscles, whereas SWE reveals that smaller muscles may take on the majority of the helmet load.

Conclusions

SWE provides a different force distribution than PID controllers. Given that the forces are derived from *in-vivo* data, it is likely that SWE muscle forces are more accurate and physiologically meaningful. Thus, SWE may lead to a better understanding of the mechanisms behind neck pain and overuse injuries in fighter pilots.

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