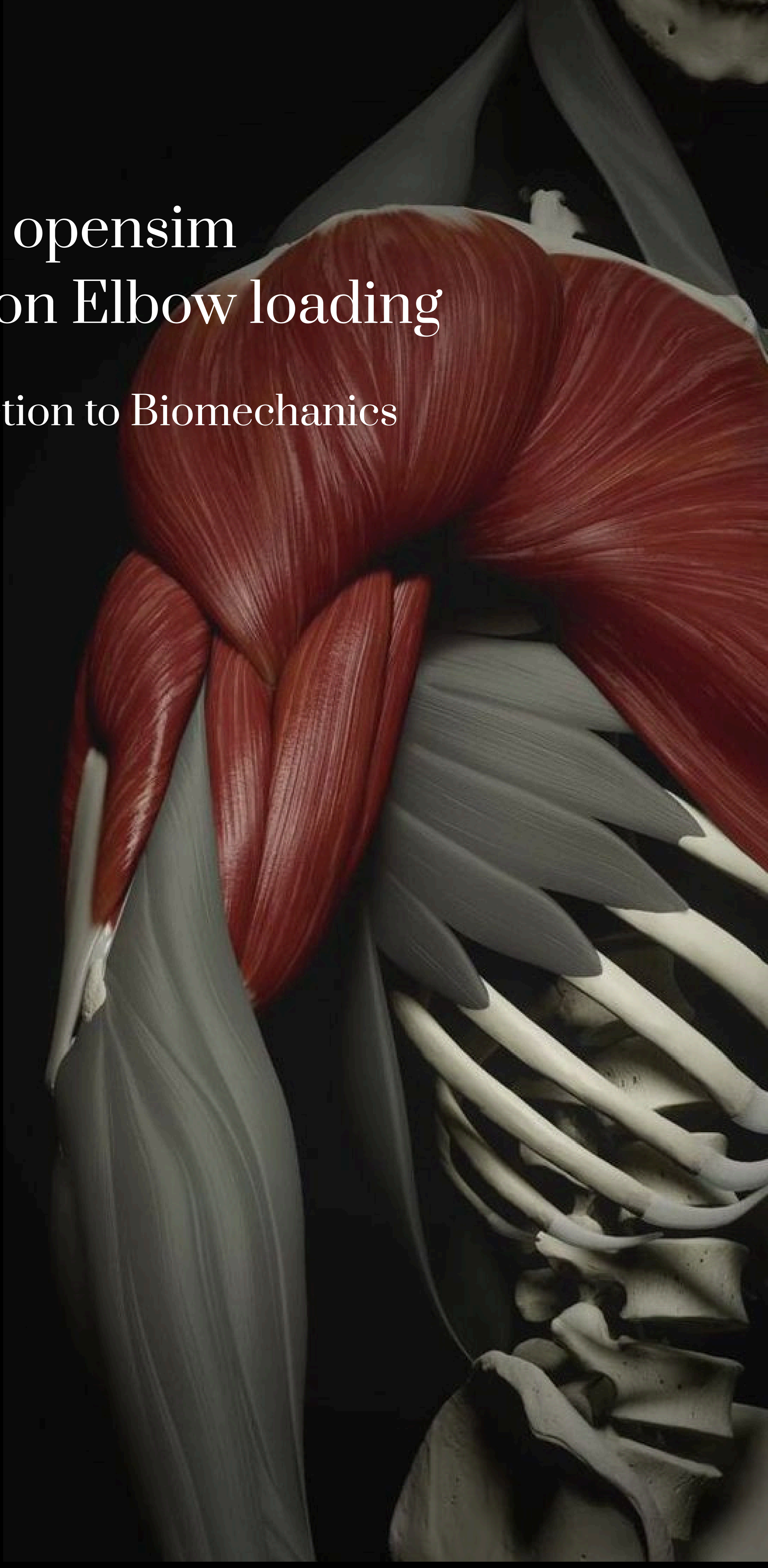
task 2_using opensim for simulation Elbow loading

course : introduction to Biomechanics
team 3



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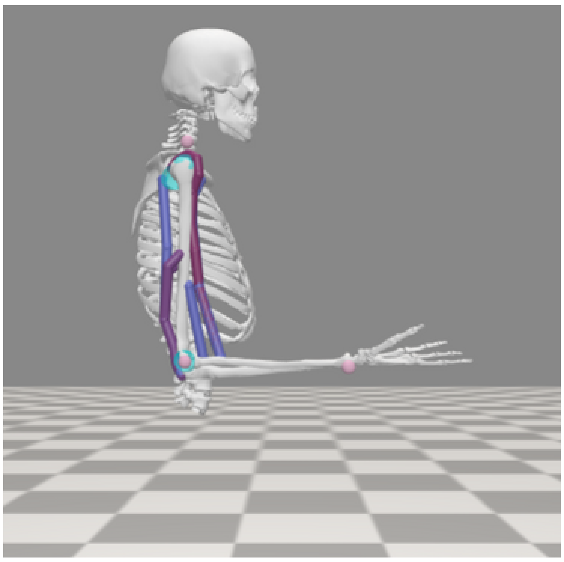
Introduction

Biomechanics uses simulations to understand how muscles, joints, and bones interact during movement. OpenSim is a widely used tool that allows researchers to model and analyze human motion. One of its key features, Computed Muscle Control (CMC), estimates the muscle activations required to follow a specific movement, such as elbow flexion.
In this task, we use the Upper Extremity model to simulate elbow loading and investigate how different factors affect movement control. These include changes to the input motion (desired kinematics), tracking task priorities, and muscle force constraints. By analyzing each modification, we can observe how the model compensates for limitations or altered priorities in muscle and joint behavior.
Comparative graphs are used to visualize joint angles, muscle activations, and tracking accuracy, helping to explain the effect of each change on the simulation results.

2. Baseline Simulation – Natural State

In the baseline simulation, the elbow movement was executed using the default kinematics, actuator constraints, and tracking tasks. This normal state serves as a reference point for assessing future modifications. A detailed analysis of muscle activations, joint kinematics, and muscle fiber behavior was conducted to understand the neuromuscular coordination during elbow flexion and shoulder movement

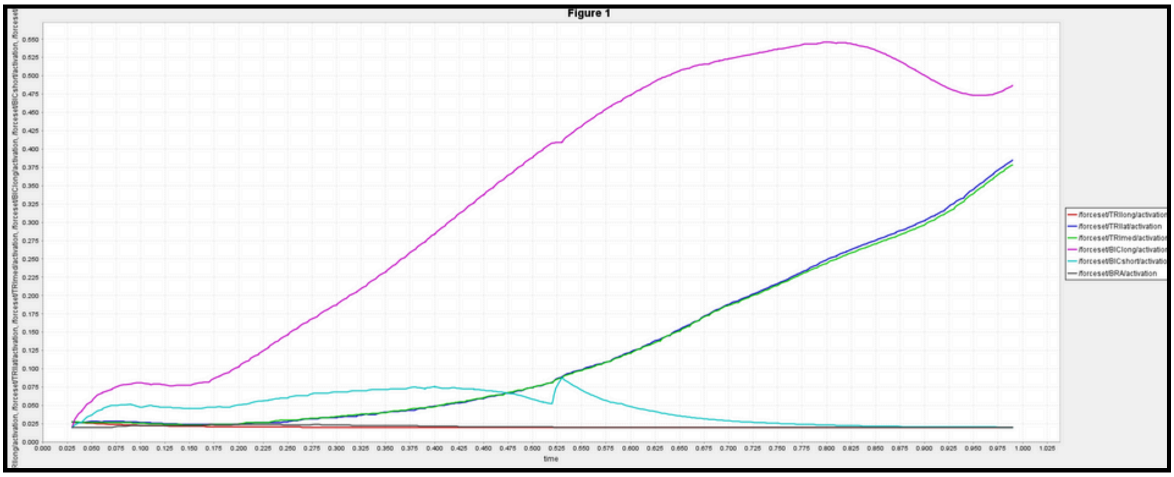


Outcome:

I. Muscle Activation Forces vs. Time

The graph 1.1 comparing the activation forces of key muscles (TRIlong, TRIlat, TRImed, BICshort, and Brachialis) reveals distinct roles:

- Biceps (BICshort) and brachialis act as primary flexors, showing elevated activations during elbow flexion.
- Triceps muscles (TRIlong, TRIlat, TRImed) serve as antagonists, remaining relatively less active but showing transient co-contractions for stabilization.
- The coordinated activation profile ensures smooth joint motion and reflects efficient neuromuscular control in a physiological setting.



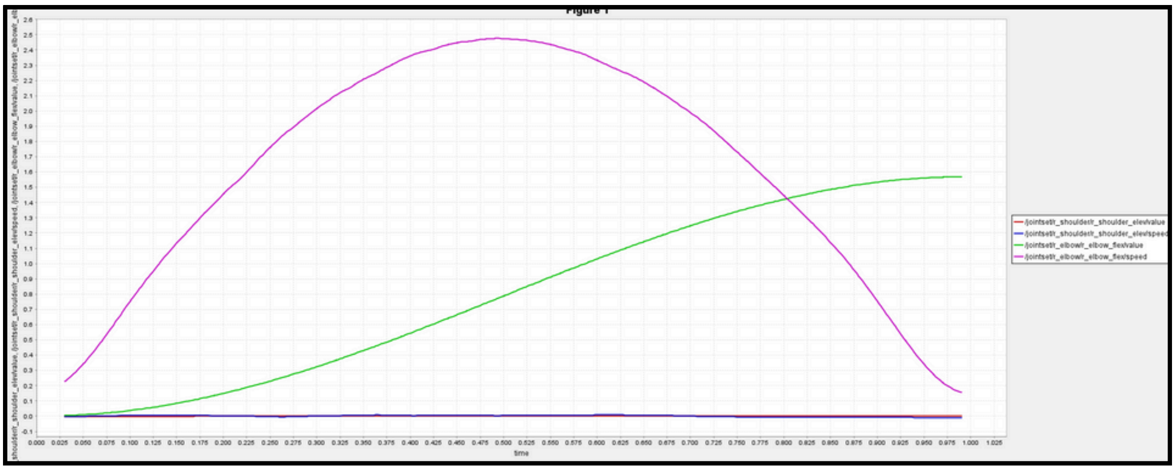
graph1.1 Muscle Activation Forces

II. Joint Angles and Speeds vs. Time

This graph 1.2 presents the joint angles and angular velocities of the elbow flexion and shoulder elevation over time during the normal state simulation. It provides insight into the quality and control of the motion pattern, confirming that it mimics realistic biomechanical behavior.

Key Points:

- Progressive Elbow Flexion:
  The elbow flexion angle increases smoothly with time, indicating a steady and natural movement without abrupt transitions. This implies effective muscle coordination during flexion.
- Slight Shoulder Elevation:
  The shoulder elevation shows only modest changes, suggesting that the shoulder joint plays a secondary role in the task. Most of the motion is concentrated in the elbow.
- Stable Angular Velocities:
  The velocity curves show a smooth pattern of acceleration and deceleration, especially for the elbow. This reflects controlled motion, avoiding any jerky or unnatural changes, which aligns with physiological expectations.



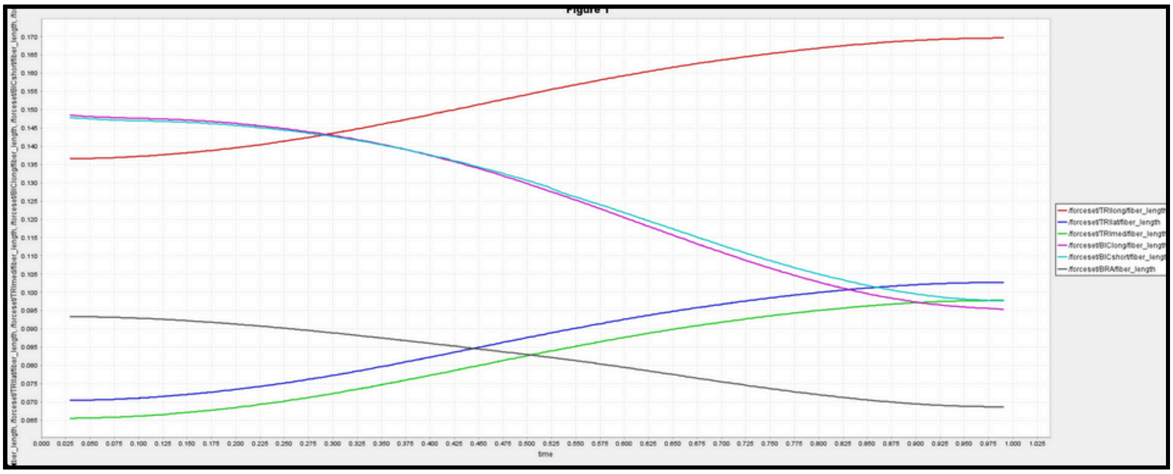
graph1.2 shoulder & elbow speed & angle

III.Muscle Fiber Lengths vs. Time

The graph 1.3 illustrates the temporal evolution of muscle fiber lengths for key elbow flexors and extensors—TrlLong, TrlLat, TrlMed, BIC-long, BIC-short, and Brachialis—under the default simulation settings, where no constraints were applied to tracking weights or actuator controls.

Key Points:

-) Triceps Group (TrlLong, TrlLat, TrlMed):
- These extensors demonstrate synchronized lengthening and shortening patterns corresponding to the elbow flexion-extension cycle.
- Fiber length decreases during elbow extension phases, reflecting concentric contraction, and increases during flexion due to eccentric loading.
-) Biceps Group (BIC-long and BIC-short):
- BIC-long shows more pronounced fiber length changes due to its bi-articular role (spanning both shoulder and elbow joints).
- BIC-short, being mono-articular, exhibits a fiber length pattern more tightly coupled with elbow flexion alone.
- Both muscles shorten during elbow flexion and lengthen during extension, consistent with their function as primary flexors.
-) Brachialis:
- As a mono-articular elbow flexor, it displays a relatively stable and consistent fiber length pattern, with predictable shortening during flexion and lengthening during extension.
- Its curve appears smoother compared to BIC-long, reflecting its isolated role.



graph1.3

Muscle fiber length

3.Changes

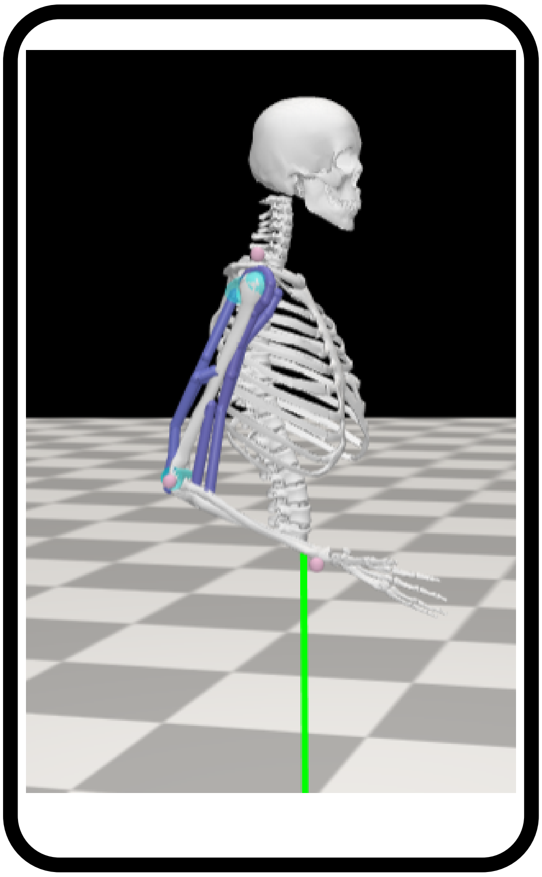
1– Modify Tracking Tasks

What Was Done:

The tracking weight for the shoulder joint (r_shoulder_elev) was set to zero, effectively removing it from the Computed Muscle Control (CMC) tracking objectives. This adjustment was made to isolate elbow joint motion and observe how the simulation responds when shoulder control is de-emphasized.

What Happens During the Simulation:

- The elbow joint closely follows the desired kinematic trajectory due to its maintained tracking priority.
- The shoulder joint drifts noticeably and lacks coordinated motion, as it is no longer being actively tracked.
- Shoulder muscles are either inactive or contribute minimally, leading to unnatural movement of the upper arm.
- While elbow motion remains accurate, the overall movement becomes biomechanically unrealistic due to the absence of shoulder stabilization.



Outcome:

I.Muscle Activation of BIClong and BICshort

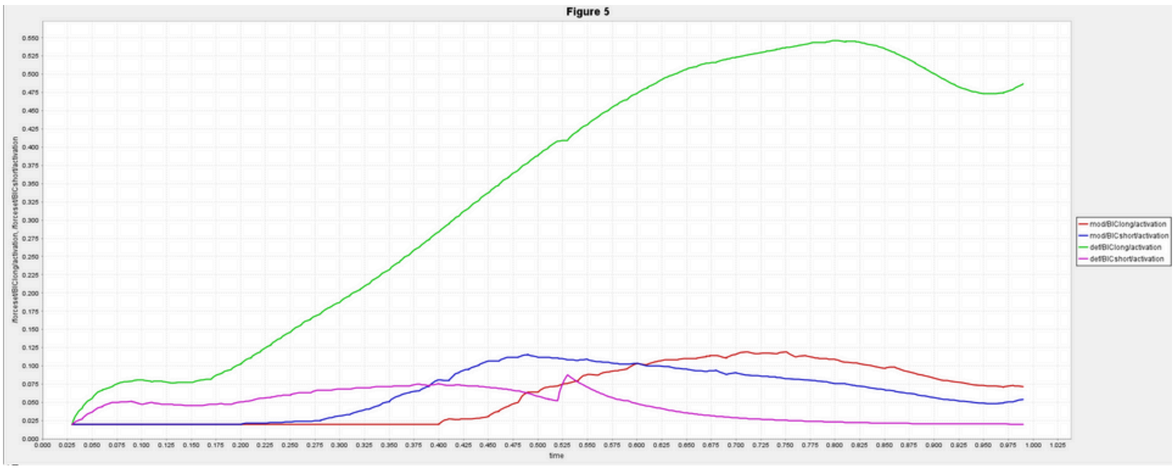
Graph 2.1 illustrates the muscle activation patterns of BIClong and BICshort over time during Computed Muscle Control (CMC) simulations under two configurations:

- Default: with r_shoulder_elev tracking weight set to 1.0.
- Modified: with r_shoulder_elev tracking weight reduced to 0.0.

By displaying both activation curves on the same graph, the comparison clearly demonstrates how muscle coordination changes when the shoulder joint is no longer actively tracked.

Observations and Analysis:

-BIClong Activation:
In the default case, BIClong shows higher activation, supporting both elbow flexion and shoulder stabilization. In the modified case, its activation decreases, reflecting less demand for shoulder stabilization once the shoulder elevation is not tracked.
-BICshort Activation:
BICshort, mainly involved in elbow flexion, shows similar activation in both cases. A slight increase in the modified case may indicate compensation for the reduced BIClong activation to maintain elbow flexion.



graph2.1 Bic(long & short), modify VS normal

II.Muscle Activation of of the Trllong, Trllat, and Trlemd muscles :

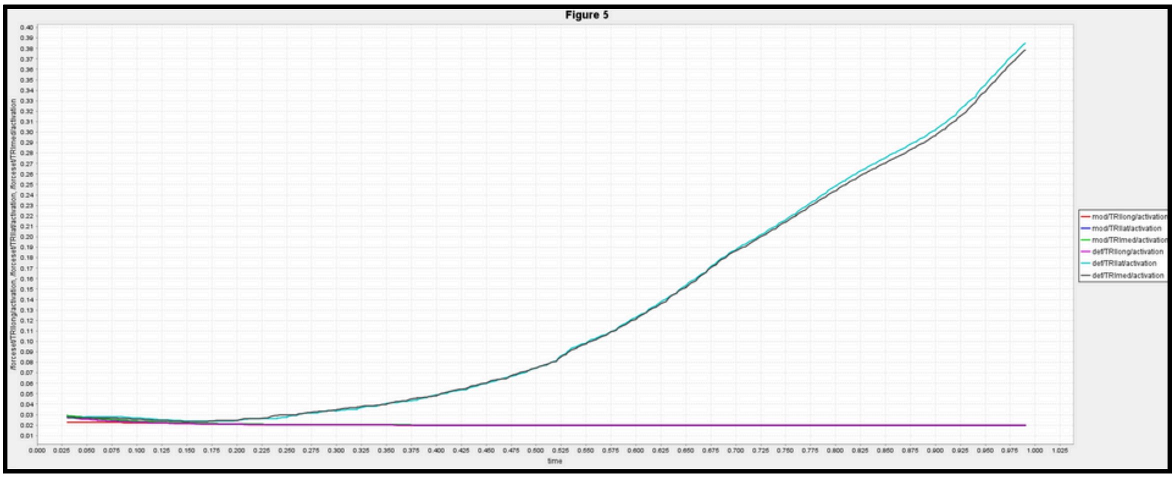
Graph 2.2 illustrates the time-varying activations of the Trllong, Trllat, and Trlemd muscles durin the Computed Muscle Control (CMC) simulations under two scenarios:

- Normal Configuration: where shoulder tracking is fully prioritized.
- Modified Configuration: where the shoulder tracking weight is reduced to 0.0.

By comparing the activation profiles of these three muscles across both conditions, the graph highlights how the redistribution of muscle activations occurs when the shoulder joint is no longe actively tracked.

Observations and Analysis:

- Trllong: In the normal configuration, the Trllong activation profile shows a steady contribution to shoulder stabilization. In the modified configuration, its activation is reduced, as it no longer plays a significant role in stabilizing the shoulder.
- Trllat: The Trllat muscle shows a similar trend, with reduced activation in the modified case. This reduction reflects the shift in control dynamics when shoulder tracking is deprioritized.
- Trlemd: The Trlemd muscle activation shows a noticeable change in the modified configuration, possibly due to compensation for the loss of shoulder stabilization and movement tracking.



graph2.2 TRi(long & short), modify VS normal

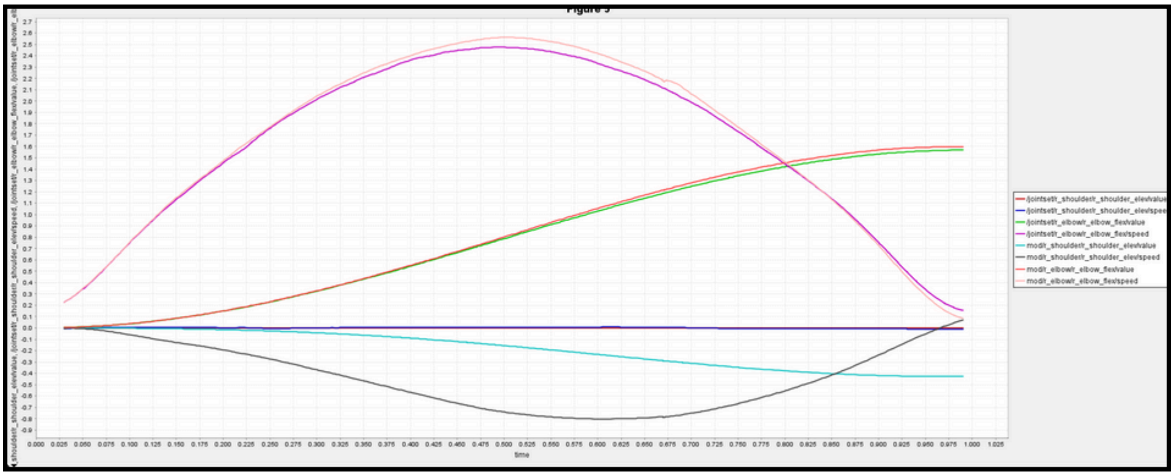
III.values of joint set and the speeds

Graph 2.3 presents the time-varying values of joint set and the speeds of shoulder elevation and r-elbow flexion under two configurations:

- Normal Configuration: where shoulder tracking is fully prioritized.
- Modified Configuration: where shoulder tracking weight is reduced to 0.0.

Observations and Analysis:

- Joint Set Values:
- In the normal configuration, joint set values are consistent with the expected kinematic pattern, with coordinated motion between shoulder elevation and r-elbow flexion. In the modified configuration, the joint set values show a deviation due to the reduced shoulder tracking weight, reflecting the altered dynamic control.
- Shoulder Elevation Speed:
- The speed of shoulder elevation decreases significantly in the modified configuration, indicating a loss of control over the shoulder motion as it is no longer prioritized for tracking.
- r-Elbow Flexion Speed:
- The speed of elbow flexion shows slight adjustments between the two configurations. Although the joint value remains relatively unaffected, the speed variations suggest compensatory changes in elbow motion due to the lack of shoulder tracking.



graph2.3 shoulder & elbow(long & short), modify VS normal

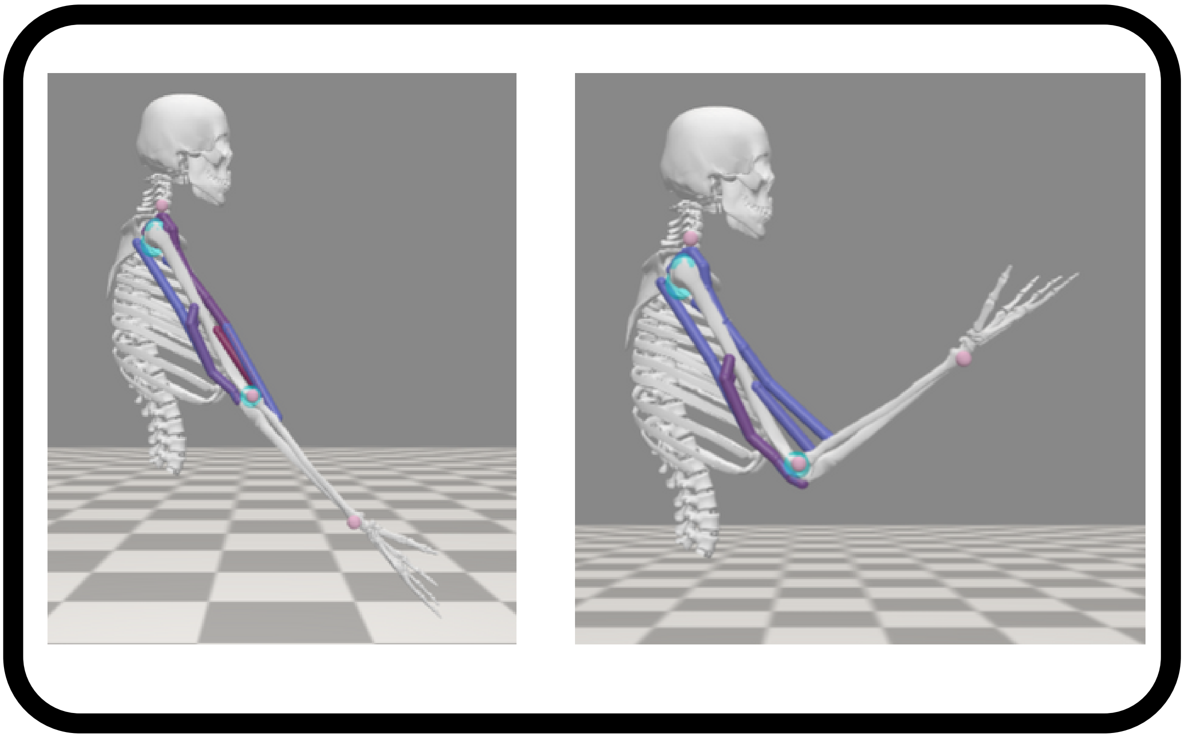
3.Changes 2– Changing the Desired Kinematics

What Was Done:

The shoulder motion was replaced by copying elbow motion into the shoulder elevation column (unnatural pattern).

What Happens During the Simulation:

- Muscles try to follow the new unrealistic motion.
- High demand on shoulder muscles (deltoid, trapezius).
- Increased control error in the elbow joint due to coordination overload.
- Greater energy expenditure and unbalanced movement.



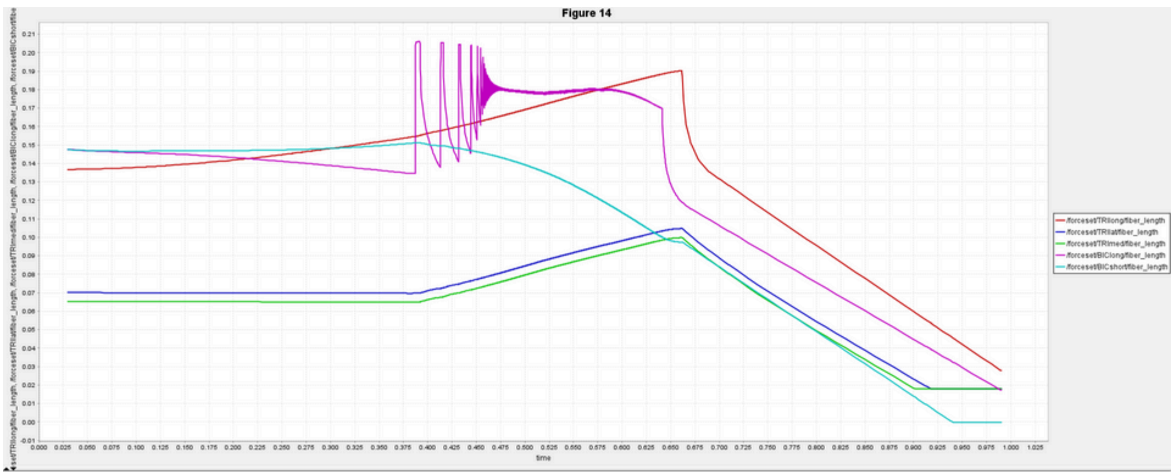
Outcome:

I.Muscle Fiber Lengths vs. Time

Graph 3.1 illustrates the time-varying activations of the Trllong, Trllat, Trlemd, BIC long, and BIC short muscles during the simulation with the modified condition, where the angles of the elbow and shoulder are reversed.

Observations and Analysis:

- Trllong (Long Head of Triceps):
- After reversing the shoulder and elbow angles, the fiber length of Trllong shows a significant increase, especially during the flexion phase. This indicates that the muscle adapts to the modified joint angles by lengthening more to stabilize both the shoulder and elbow. The muscle works harder to support the upper limb in this altered posture.
- Trllat (Lateral Head of Triceps):
- Trllat exhibits a similar trend with an increase in fiber length, but the change is less pronounced compared to Trllong. The lateral head responds to the altered shoulder position, primarily supporting the elbow joint extension, with smaller adjustments in fiber length.
- Trlemd (Medial Head of Triceps):
- For Trlemd, there is minimal change in fiber length. Since this muscle mainly contributes to elbow extension, the reversal of angles does not significantly affect its activation. It maintains relatively stable fiber lengths throughout the motion, showing less sensitivity to the modified joint configuration.
- BIC long (Long Head of Biceps):
- BIC long shows a notable change in fiber length, especially during elbow flexion. This muscle experiences greater elongation when the elbow is flexed in the new configuration, indicating a higher demand for muscle activation to maintain the flexion posture and accommodate the altered angle requirements.
- BIC short (Short Head of Biceps):
- BIC short shows minimal variation in fiber length. As this muscle primarily assists in elbow flexion, the change in the joint angles has less impact on its activation. It remains relatively consistent in its fiber length during the simulation.



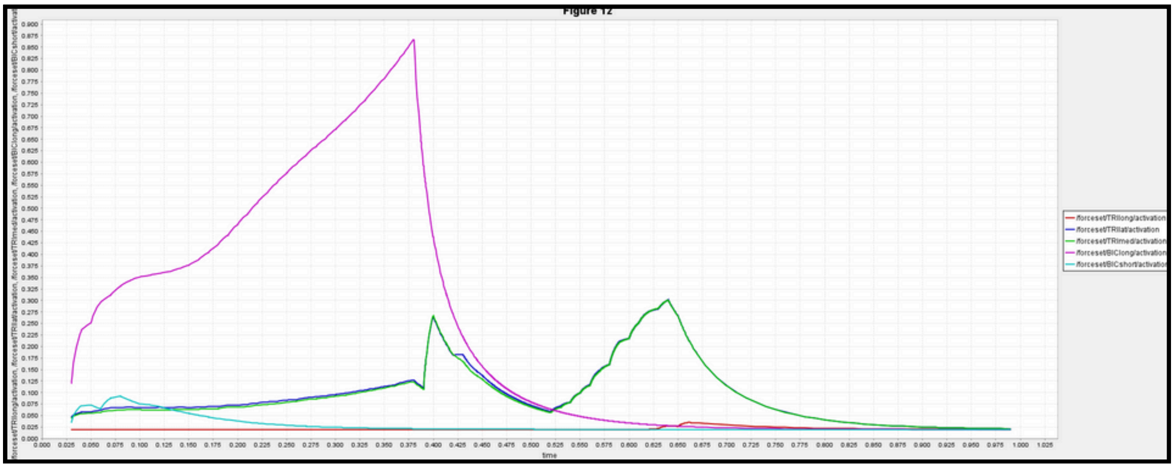
graph3.1 Muscle Fiber Lengths

II.Muscle Activation of of the Trllong, Trllat, and Trlemd muscles :

Graph 3.2 illustrates the time-varying activations of the Trllong, Trllat, Trlemd, BIC long, and BIC short muscles during the simulation with the modified condition, where the angles of the elbow and shoulder are reversed.

Observations and Analysis:

- Trllong, Trllat, and Trlemd Activation:
- The activation profiles of the Trllong, Trllat, and Trlemd muscles show noticeable shifts when the shoulder and elbow angles are reversed. These muscles, which typically contribute to shoulder stability and elbow extension, exhibit altered activation patterns. The shifts in their activation indicate the system's attempt to compensate for the altered joint configuration and maintain the kinematic movement.
- BIC Long and BIC Short Activation:
- The BIC long and BIC short activations are significantly affected by the reversal of elbow and shoulder angles. BIC long, which is typically involved in both shoulder stabilization and elbow flexion, displays a sharp decrease in activation due to the change in elbow configuration. Conversely, BIC short, primarily responsible for elbow flexion, shows a slight increase in activation as it compensates for the altered biomechanics.



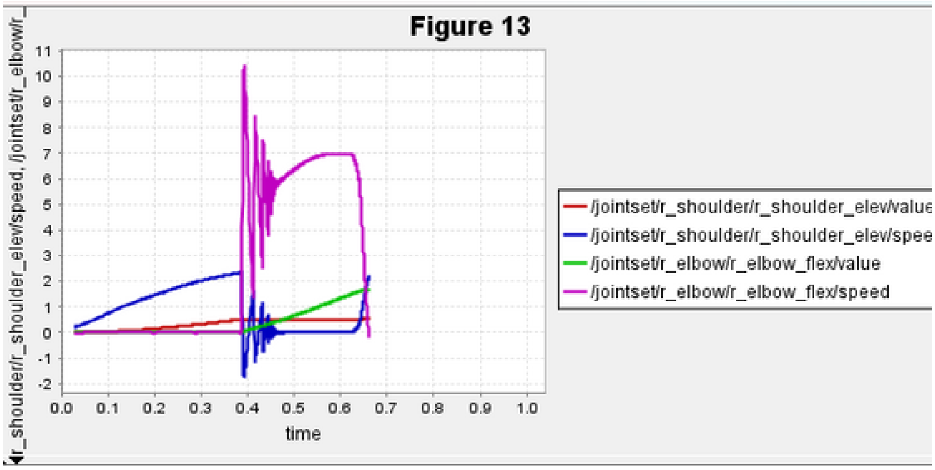
graph3.2 Muscle Activation

III.values of joint set and the speeds

Graph 3.3 presents the time-varying values and speeds of R-Shoulder and R-Elbow Flexion joint angles during the simulation with the modification of reversing the elbow and shoulder angles.

Observations and Analysis:

- R-Shoulder Joint Value and Speed:
- The R-Shoulder joint values show significant alterations in the trajectory when the angles are reversed. The speed profile for shoulder movement demonstrates increased variability, likely due to the need for compensatory adjustments in the shoulder muscles to maintain stability and control in the altered configuration. The deviation from normal shoulder movement suggests the biomechanical challenges introduced by this modification.
- R-Elbow Flexion Joint Value and Speed:
- The R-Elbow Flexion joint exhibits notable changes in its value as well, with the modified configuration influencing the elbow's range of motion and its dynamic behavior over time. The speed profile of the R-Elbow Flexion reflects adjustments made by the system in response to the altered configuration. The flexion movement, while still functional, shows a delayed or adjusted acceleration phase, indicative of the muscle forces compensating for the changed elbow angle.



graph3.3 Shoulder and elbow angles & speed

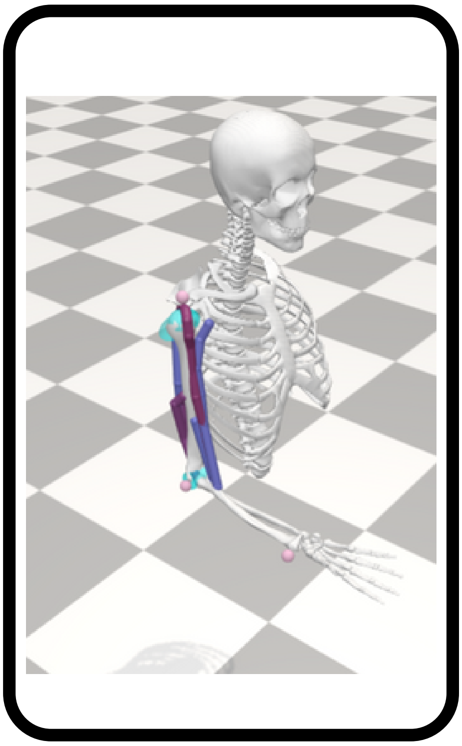
3.Changes 3– Limiting Biceps Long Head Force

What Was Done:

In this simulation, the control constraint on the BIC-long actuator was reduced by setting its maximum excitation (control) to 0.05, significantly limiting the muscle's ability to generate force.

What Happens During the Simulation:

- Reduced Torque Generation:
- The BIC-long muscle becomes almost inactive and unable to generate the necessary torque for elbow flexion and shoulder stabilization.
- Compensatory Strategies:
  - Other elbow flexors, such as brachialis and BIC-short, increase their activity to maintain elbow function.
  - Shoulder muscles, particularly the deltoid and triceps (in eccentric mode), assist in stabilizing and moving the arm.
- Kinematic Consequences:
  - Elbow flexion becomes uncoordinated, sometimes appearing jerky or delayed, especially during periods when BIC-long would normally play a major role.
  - Shoulder motion may become less stable due to the reduced dual-joint contribution of BIC-long.
- Changes in Muscle Activation:
  - Increased activation in secondary muscles is observed, indicating a redistribution of neuromuscular effort.
  - These changes result in increased overall muscle load and can lead to less efficient movement.



Outcome:

I.Muscle Fiber Lengths vs. Time

Graph 4.1 presents the time-varying fiber lengths of the BIC-long and BIC-short muscles throughout the motion cycle under two simulation configurations:

- Normal Configuration: The BIC-long actuator functions without restriction, with a maximum control (excitation) value of 1.0, allowing it to fully participate in elbow flexion and shoulder stabilization.
- Modified Configuration: The BIC-long actuator is constrained to a maximum control of 0.05, severely limiting its ability to contribute force or generate motion.

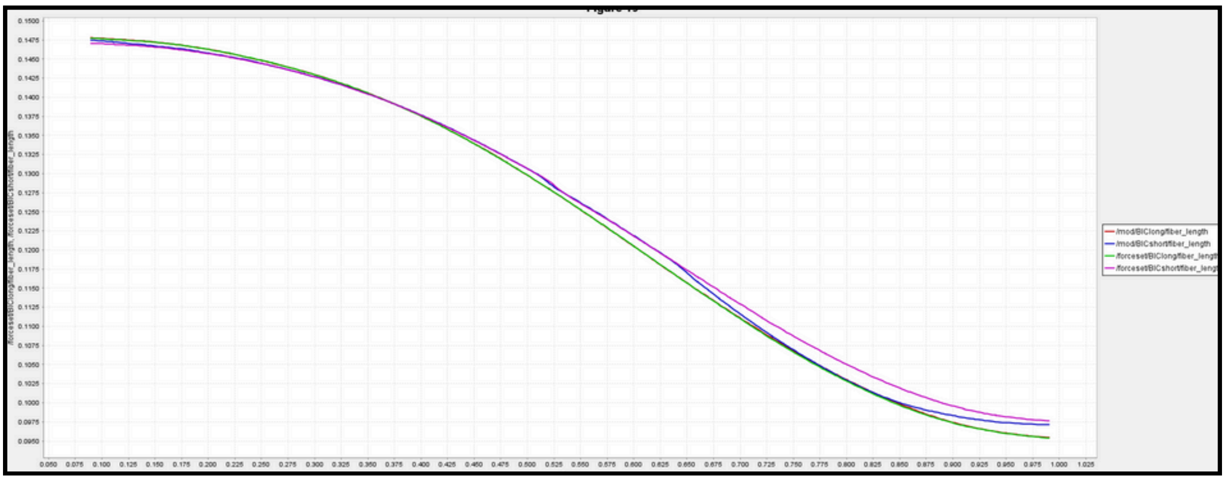
Observations and Analysis:

BIC-long Muscle:

- In the normal case, the BIC-long fiber length decreases in a coordinated pattern, consistent with active shortening during elbow flexion. This behavior reflects its dual role in elbow flexion and minor involvement in shoulder stabilization.
- In the modified condition, the fiber length trajectory of BIC-long is noticeably altered. The muscle shows less pronounced shortening, with a flatter curve—indicating that it is largely passive throughout the motion. This is a direct result of the excitation cap preventing normal contractile activity.

BIC-short Muscle:

- As BIC-short primarily contributes to elbow flexion, it maintains a relatively similar fiber length pattern in both configurations.
- However, a slight shift or increased rate of fiber shortening may be observed in the modified configuration. This suggests that BIC-short may be compensating for the limited contribution of BIC-long to preserve elbow joint kinematics.



graph4.1 Muscle Fiber Lengths

II.Muscle Activation of the Biclong and Bic short muscles :

Graph 4.2 illustrates the time-varying muscle activations of BIC-long and BIC-short during the motion cycle, comparing two configurations:

- Default Configuration: BIC-long operates without constraint (max control = 1.0).
- Modified Configuration: BIC-long is limited to a maximum control of 0.05, restricting its ability to activate.

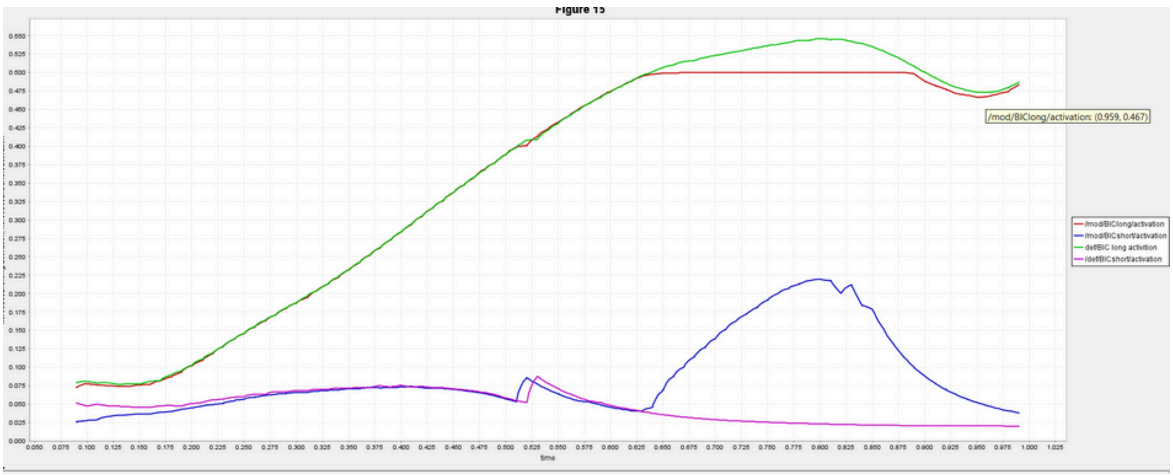
Observations and Analysis:

BIC-long Activation:

- In the default condition, BIC-long exhibits a prominent activation profile, indicating its dual role in both elbow flexion and shoulder stabilization.
- When the activation is constrained to a maximum of 0.05, the BIC-long muscle becomes nearly inactive, as seen by the flat and minimal activation trace. The control algorithm avoids using it for motion generation due to the imposed limit.

◆ BIC-short Activation:

- BIC-short remains active across both conditions as it primarily contributes to elbow flexion and is not constrained.
- Under the modified condition, a notable increase in BIC-short activation can be observed, particularly during the periods of peak joint motion. This reflects a compensatory adaptation, where BIC-short assumes greater responsibility to maintain the desired elbow kinematics in the absence of full BIC-long support.



graph4.2 Muscle Activation

Conclusion

This OpenSim study examined how modifying control parameters in the arm26 model affects upper limb biomechanics, revealing three key insights:

1. Data Accuracy Matters
   Swapping shoulder and elbow angle data produced impossible joint movements, proving that proper kinematic inputs are essential for valid simulations.

2. Control Priorities Change Movement Patterns
   Removing shoulder tracking shifted motion entirely to the elbow, demonstrating how muscle coordination adapts when joint priorities are altered.

3. Muscles Compensate for Limitations
   Restricting biceps activation forced other muscles (like brachialis and triceps) to work harder while still achieving the movement goal.

These findings highlight the model's ability to adapt to constraints, which is useful for applications like rehabilitation therapy and assistive device design. Future work could compare these simulations with real movement data to further improve their accuracy.

Reference

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