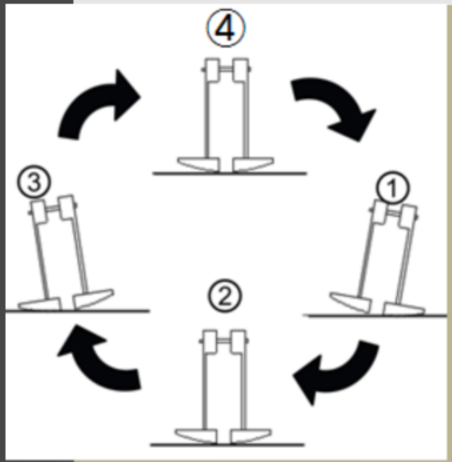
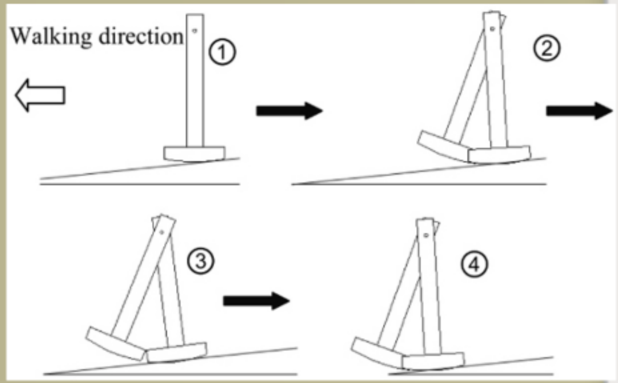
Optimization of pianists' whole-body gestures through the integration of experimental and simulation research approaches

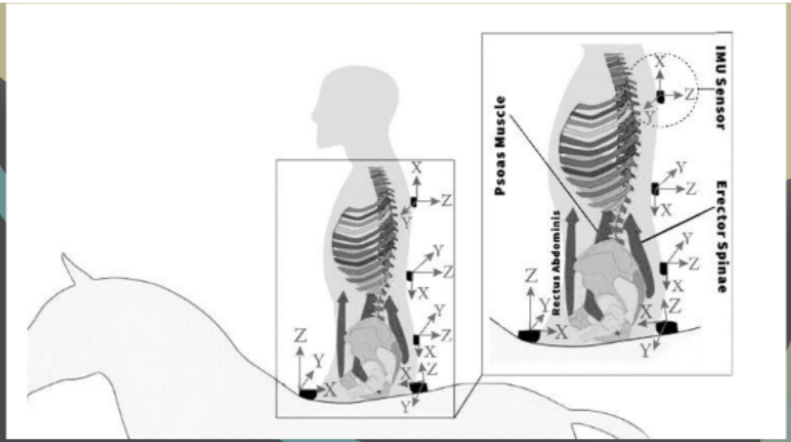
Academic Background

B.Sc.: Mathematical Modeling of a Bipedal Robot





M.Sc.: Musculoskeletal Modeling Hippotherapy



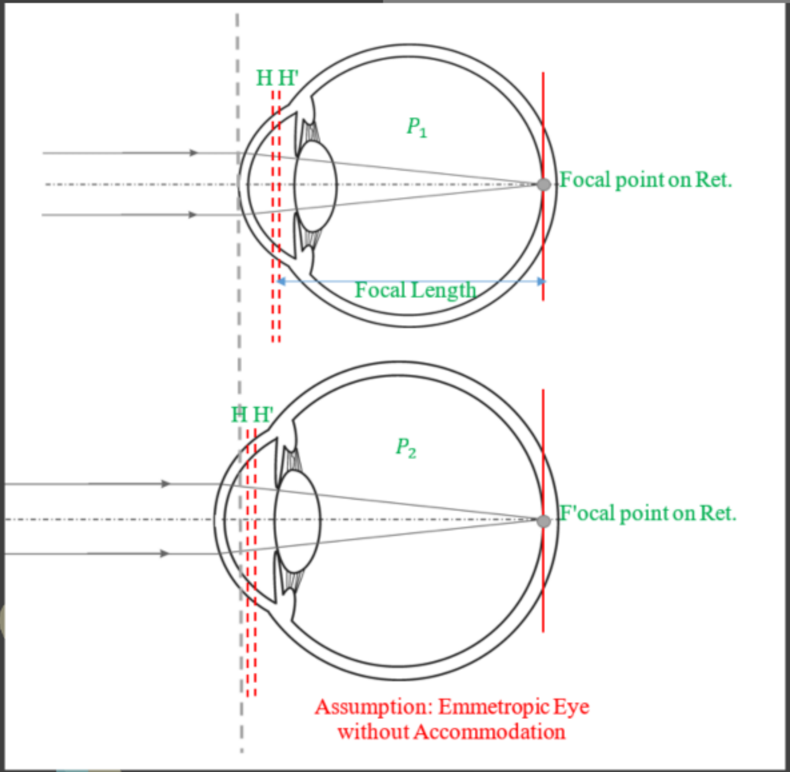
Mohammadali Shahiri

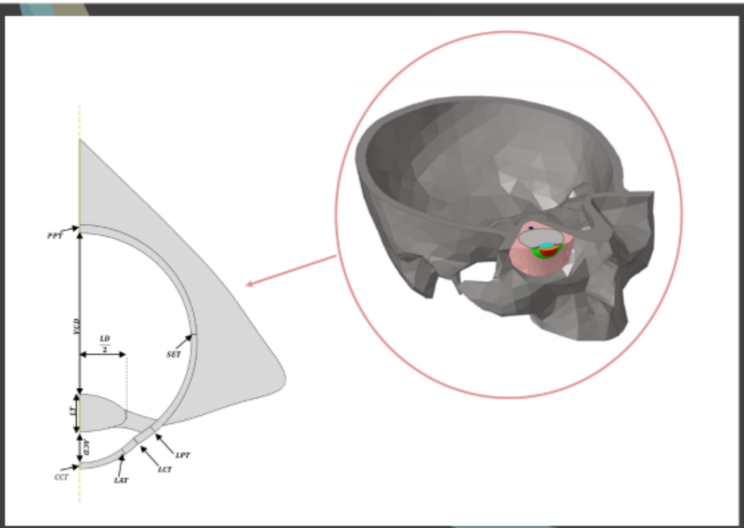
B.Sc. Mechanical Eng.

M.Sc. Biomechanical Eng.

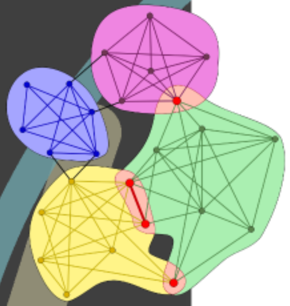
https://shahiri.in/

AFTER GRADUATION





Why Ph.D.



- Multidisciplinary approach
- Optimization
- Injury Prevention
- Computational Biomechanics
- Human Neuro-Musculoskeletal Modeling

Ph.D. Program Progress

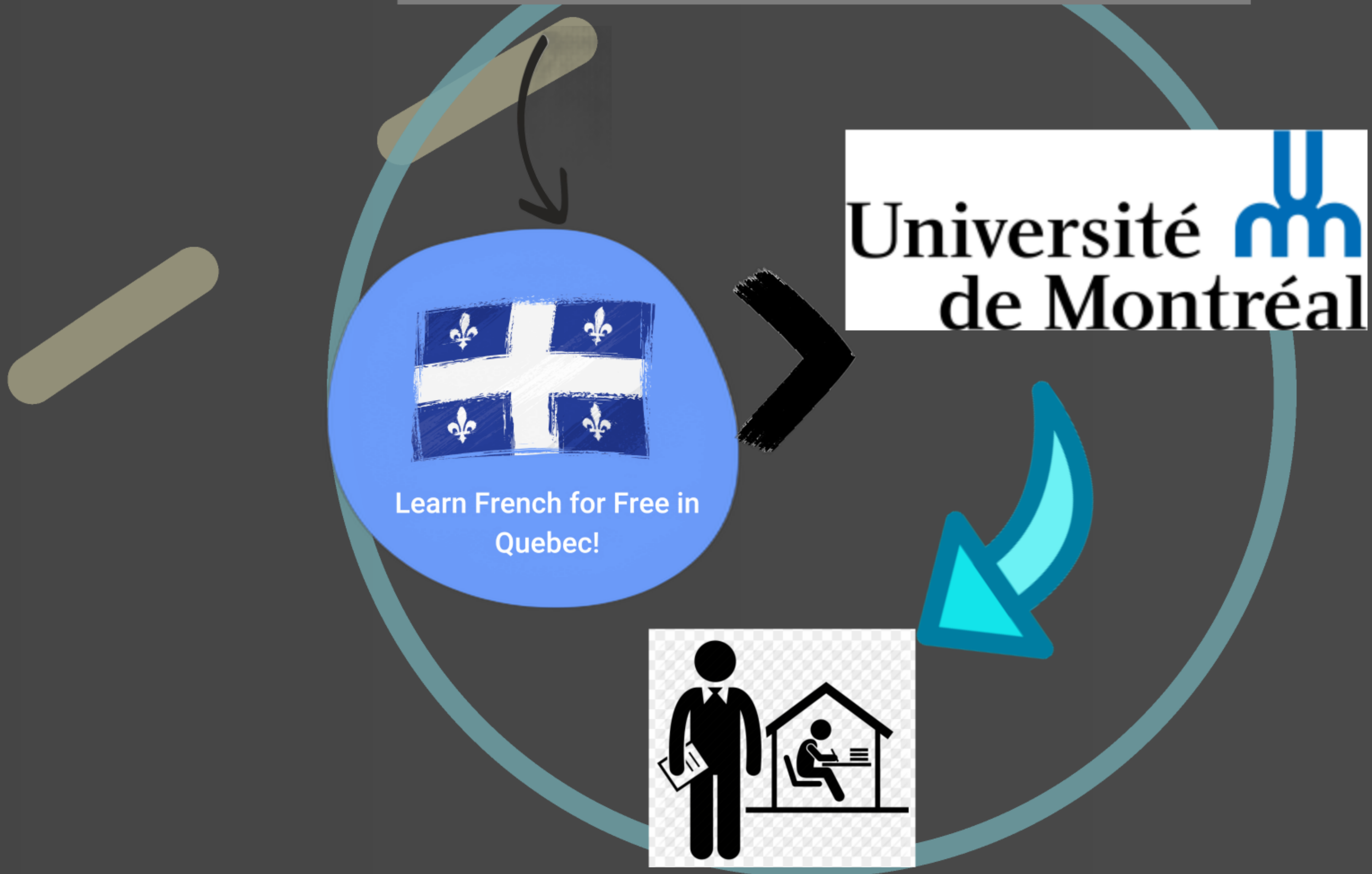
KIN 6838 - Biomécanique : modèles et analyse
KIN 7821 - Séminaire 1
KIN 6832 - Apprentissage du mouvement humain (Dropped)

KIN 6841 - Adaptation du mouvement et régulation de l'exercice (Summer 2024)
MMD 6005R - Éthique et recherche en santé (Autumn 2024)
CSS 6900 - Plan de perfectionnement en sciences de la santé (Autumn 2024)
Course at Mcgill (Autumn 2024 - Winter 2025)
KIN 7822 - Séminaire 2 (Winter 2025) ?

Optional Course (Fall 2024):
1. **BMDE 520 Machine Learning for Biomed Data (3 Credits)**
2. **BMDE 519 Biomedical Signals & Systems (3 Credits)**
3. **POTH 620 Measurement: Rehabilitation 1 (3 credits) [Winter 2025]**

EKSAP scholarship
BOURSE DE MÉRITE (AUTOMNE 2023)

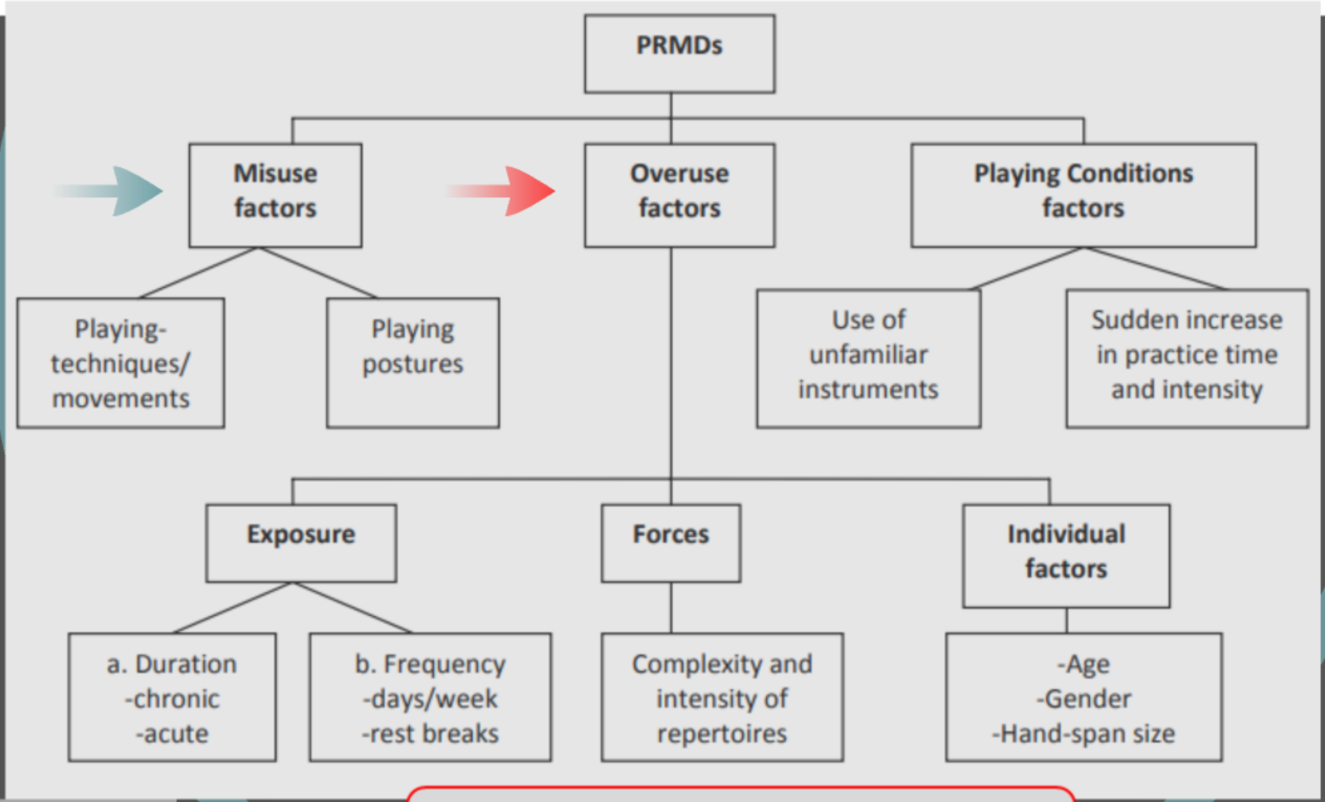
French Learning Process



- Complete required courses before May 2025 to be eligible for the **synthesis exam**
- Publish at least one **research paper**
- Apply for **FRQNT** scholarship and **Bourse d'excellence de l'EKSAP**
- looking for a **TA** position at other universities
- Looking for **internship opportunities in industry** or academia to enrich the project and gain experience **(related to my third year)**
- Continue improving **French language skills**

PhD in progress

- Prevalence of **Playing-Related Musculoskeletal Disorders** (among Pianists ranging from 40% to 90%)



Overuse vs. Misuse

Overuse emphasizes the **excessive quantity or intensity of use**.
Misuse focuses on **incorrect or improper** usage.

1. Zaza et al., 1998
2. Allsop & Ackland, 2010
3. Verdugo et al., 2020

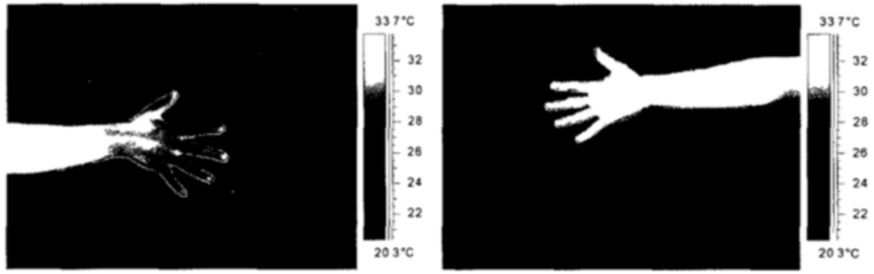
Literature:

- Using infrared imaging to evaluate piano-related injuries
- Measuring the skin temperature in 3 regions

A statistically significant difference in hand temperatures, but not in the lower arm and upper arm temperatures.

(a) (b) (c)

Selecting the regions of interest (a) the hand (b) the lower arm and (c) the upper arm.



Importance:

Non-invasive nature and potential in early injury detection

Proximal-to-Distal Sequences of Attack and Release Movements of Expert Pianists during Pressed-Staccato Keystrokes

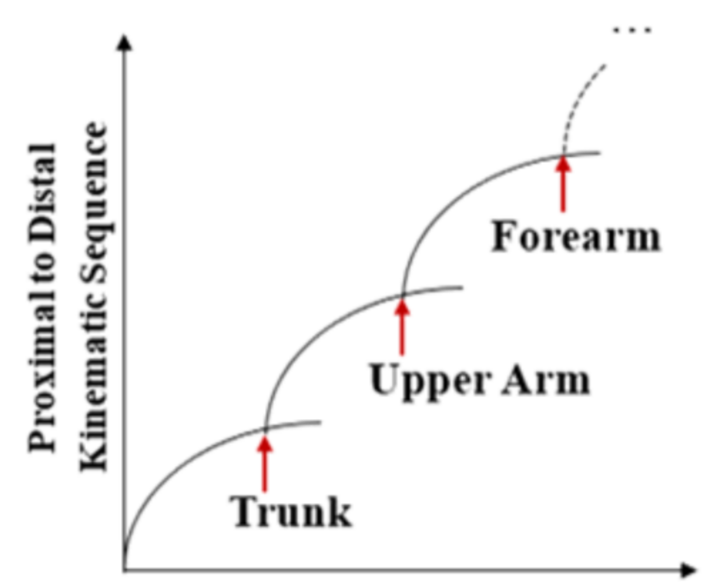
Felipe Verdugo, Mickaël Begon, Sylvie Gibet & Marcelo M. Wanderley

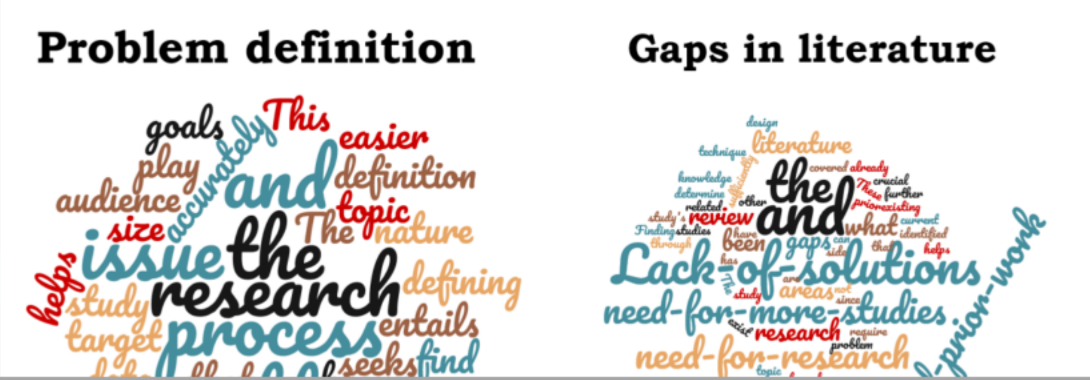
- Trunk motion can actively contribute to the generation of velocity and force at the distal end of the kinematic chain.

- Trunk motion enhancing anticipatory shoulder movements, suggesting trunk involvement might optimize performance and reduce injury risks.

Effects of Trunk Motion, Touch, and Articulation on Upper-Limb Velocities and on Joint Contribution to Endpoint Velocities During the Production of Loud Piano Tones

Felipe Verdugo[1,2,3*], Justine Pelletier[4], Benjamin Michaud[1], Caroline Traube[3,4] and Mickaël Begon[1,5]





Our Contribution:

A few studies to date have utilized **computer simulation and optimal control methods** to address the risk of musculoskeletal disorders in pianists.

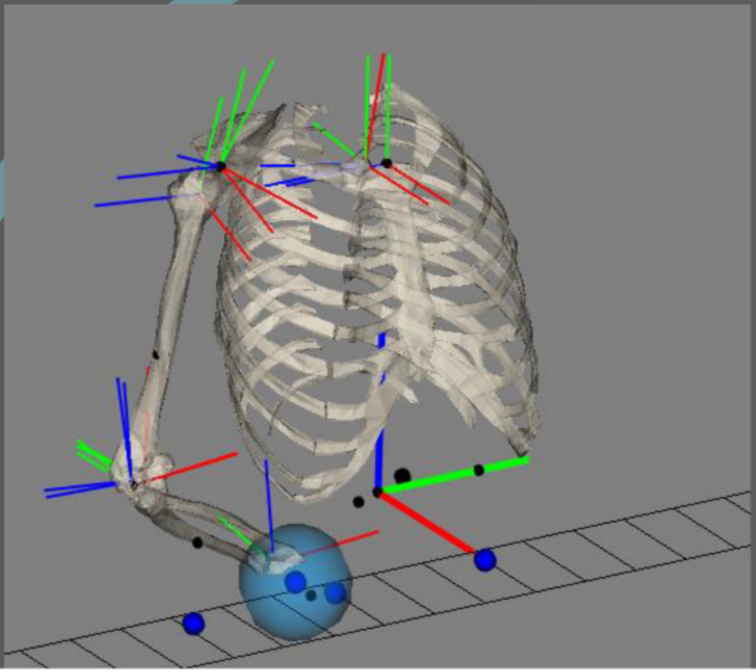
1) This innovative approach offers a unique opportunity to analyze the problem without the requirement of conducting extensive experiments involving a large sample size of participants.

2) Taking advantages of the unique capabilities of Bioptim's control algorithms (Analyzing the impact of different parameters on performance)

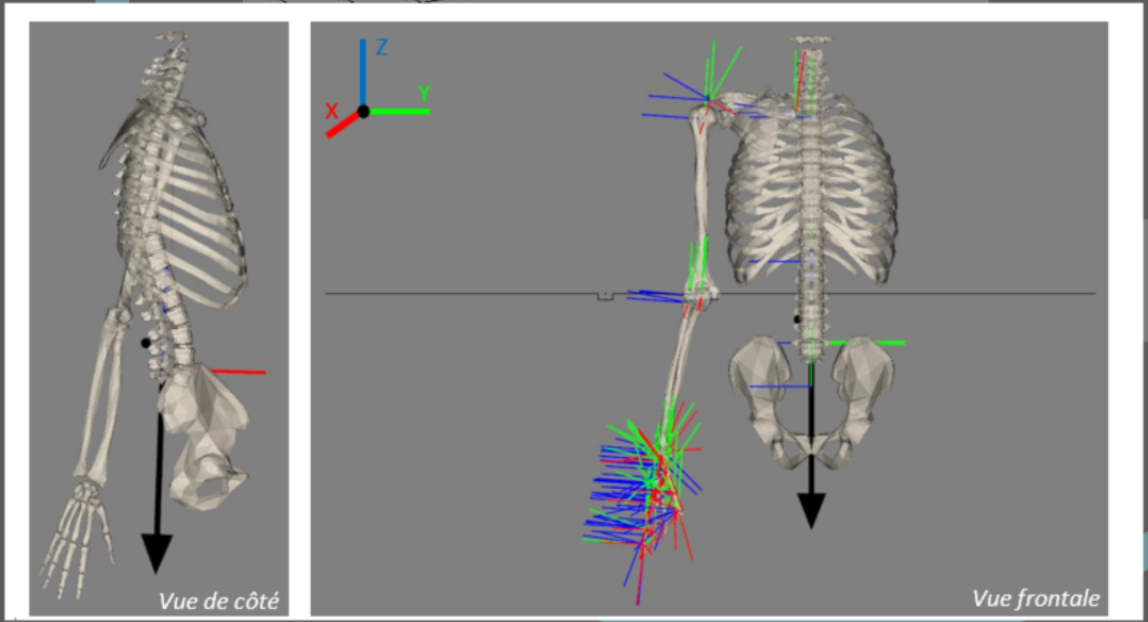
Therefore, we came to the idea of **adopting optimal control** (**Predictive Simulation**) to better understand the potential benefits of **using trunk movements** in piano performance specifically aiming **to reduce torque at distal joints**.

Traditional Piano Teaching method

Methodology:

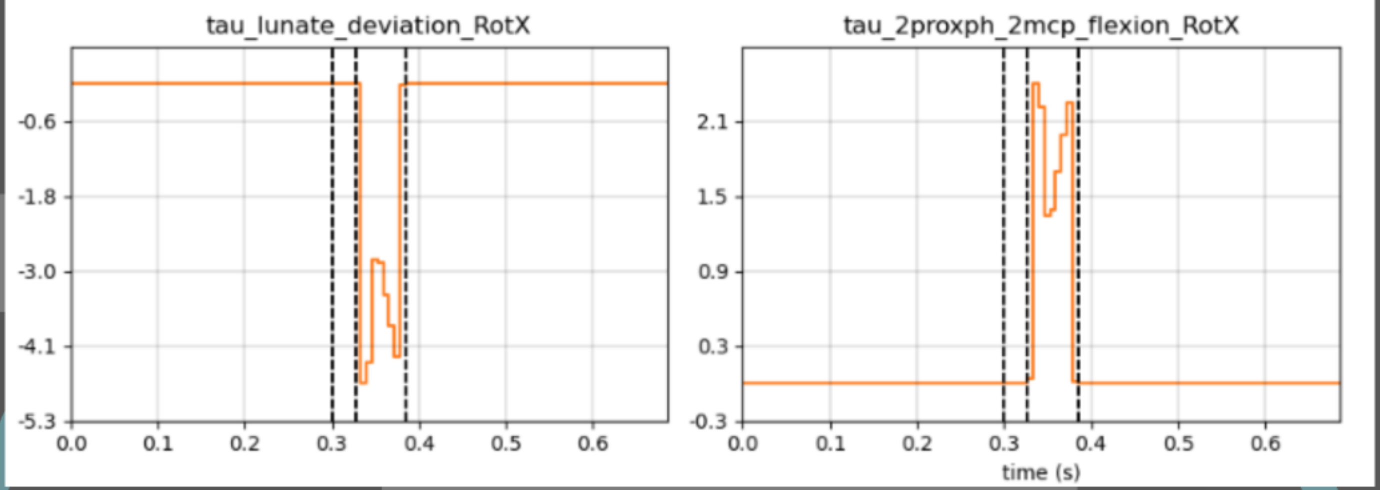


Grégoire_2021

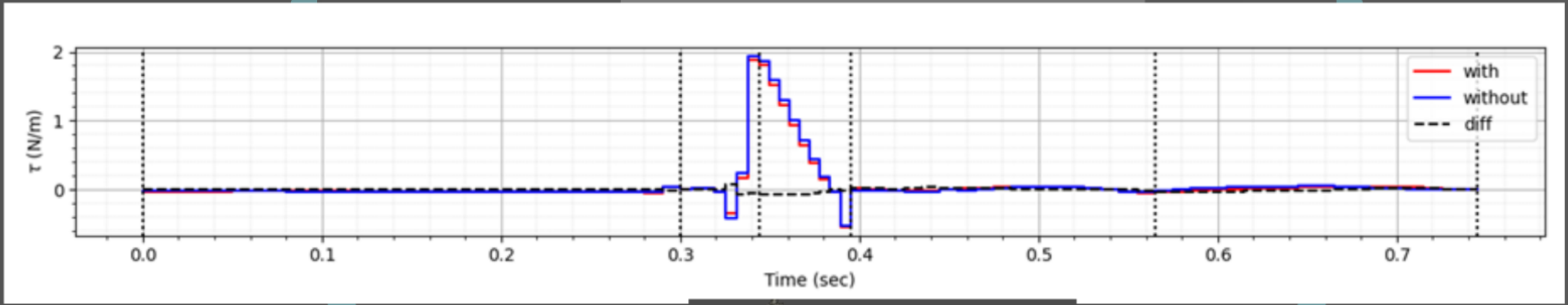


Mathilde_2022

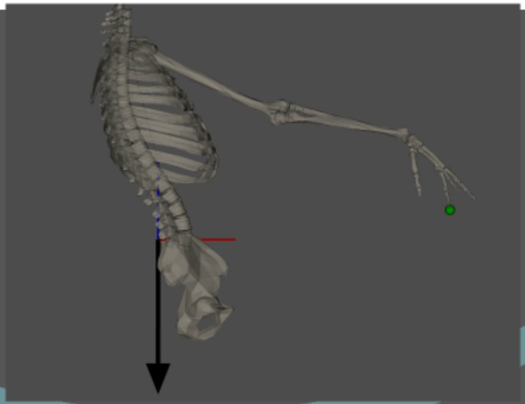
Tau-Time Graph

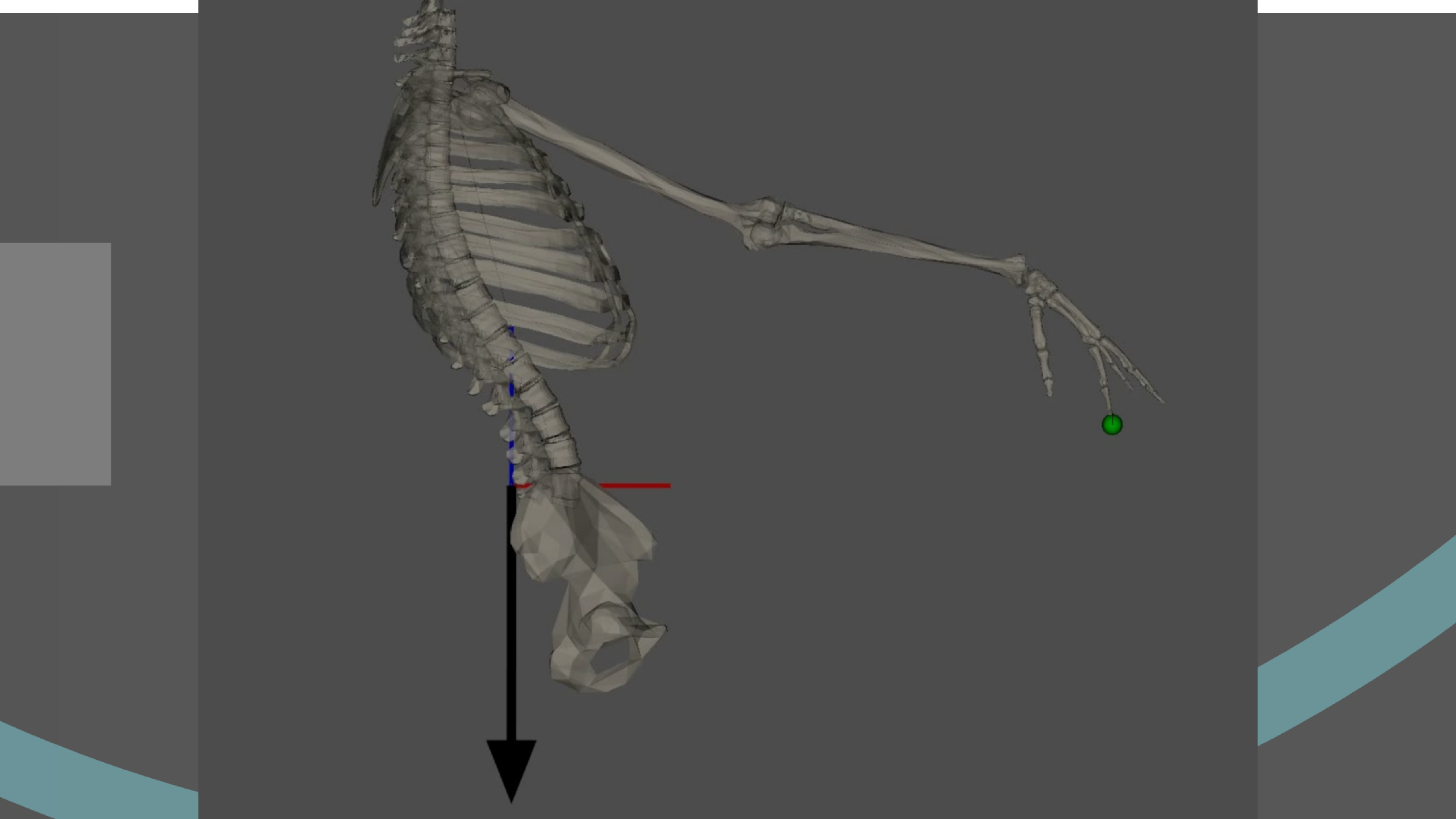


MCP and Wrist results



Posterior Mov. Pelvis

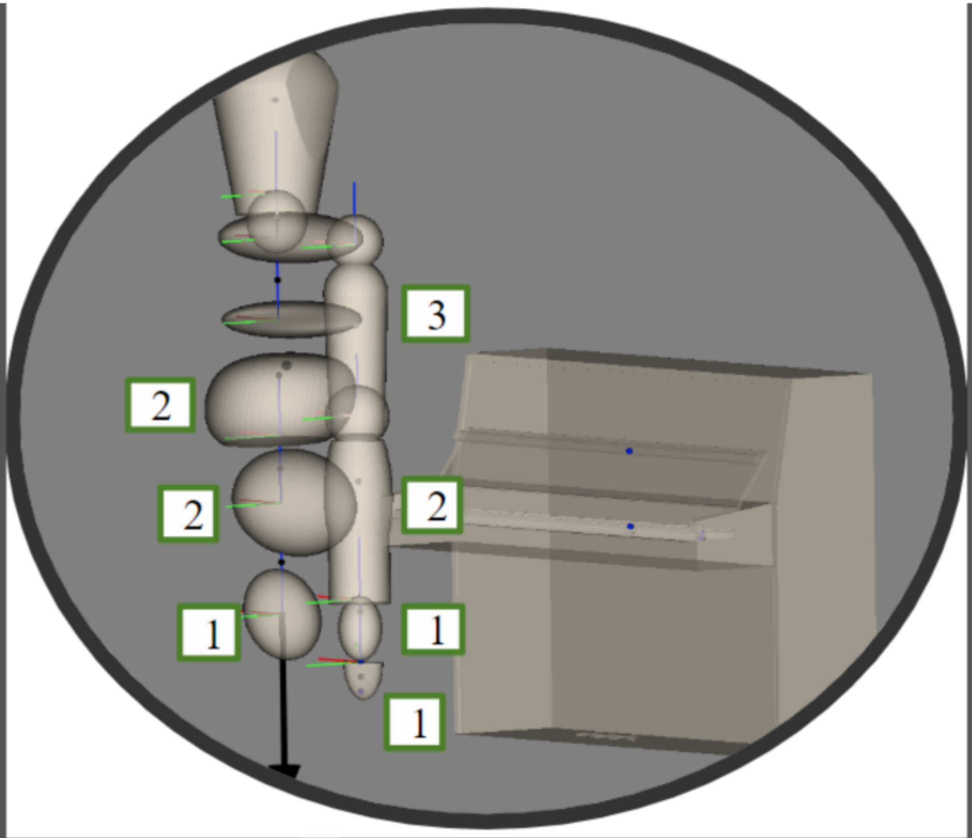




Playing Strategies

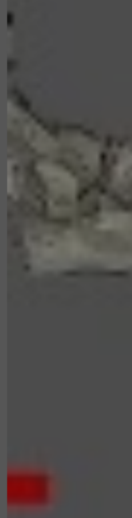
Dynamic Trunk (DT) Static Trunk (ST)

#1. Pelvic Tilt: Anterior Tilt / Posterior Tilt
#2. Thoracic Flexion/Extension
#3. Thoracic Rotation: Left / Right
#4. Upper Thoracic (Rib Cage) Flexion/Extension
#5. Upper Thoracic (Rib Cage) Rotation: Left / Right
#6|1. Shoulder Flexion/Extension
#7|2. Shoulder Abduction/Adduction
#8|3. Shoulder Internal/External Rotation
#9|4. Elbow Flexion/Extension
#10|5. Forearm Pronation/Supination
#11|6. Wrist Flexion/Extension
#12|7. Metacarpophalangeal (MCP) Flexion/Extension



The rationale behind exploring the ST strategy is to understand the biomechanical implications of limited trunk involvement, a common scenario in certain pianistic techniques and postures.

Two types of

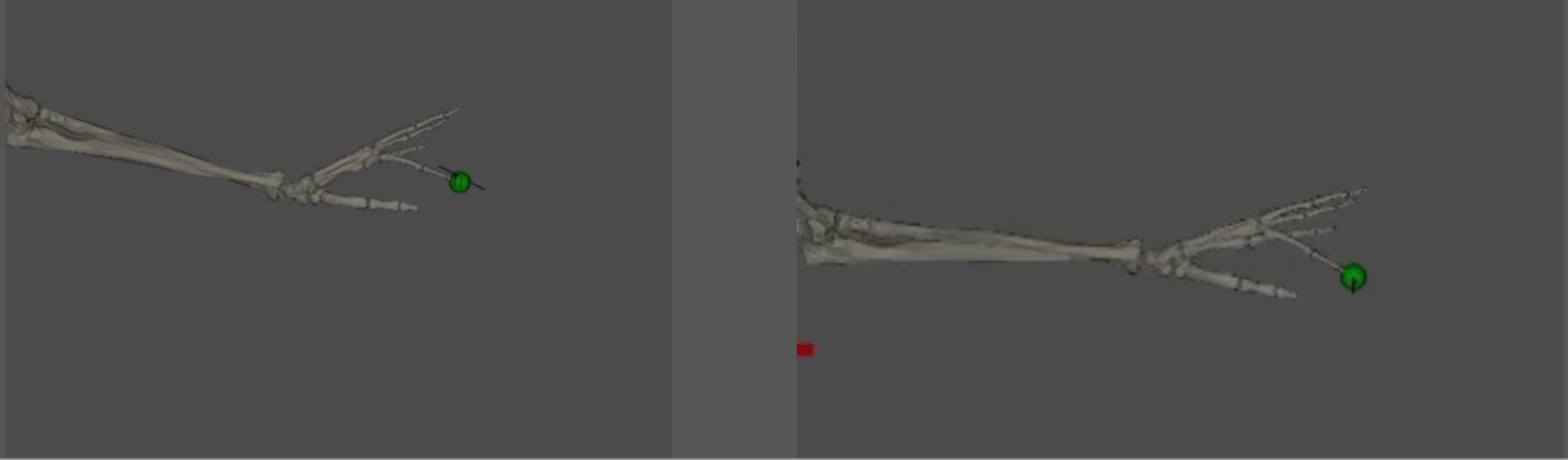


Two types of touch

because struck and pressed touches engage muscles and
e biomechanical loading and potential injury risk.

cription of movement phases:

Two types of touch



This differentiation is pivotal because struck and pressed touches engage muscles and joints differently, affecting the biomechanical loading and potential injury risk.

Description of movement phases:

Phase 1: Preparation involves the positioning of fingers above the key

Phase 2: Key Descent is the downward movement to press the key

Phase 3: Key Bed denotes the moment when the key is fully pressed

Phase 4: Key Release is the upward movement to release the key

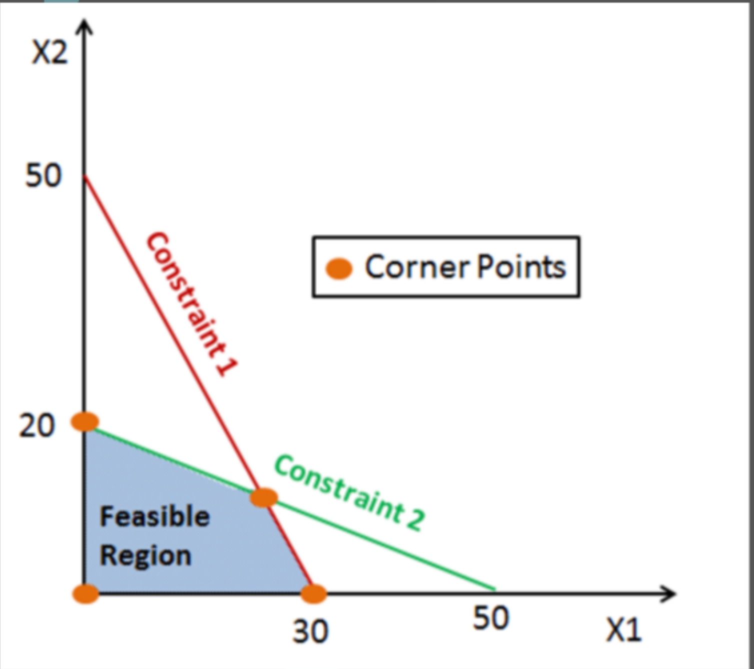
Phase 5: Return to Neutral refers to the reversion to the starting position, ready for subsequent actions.

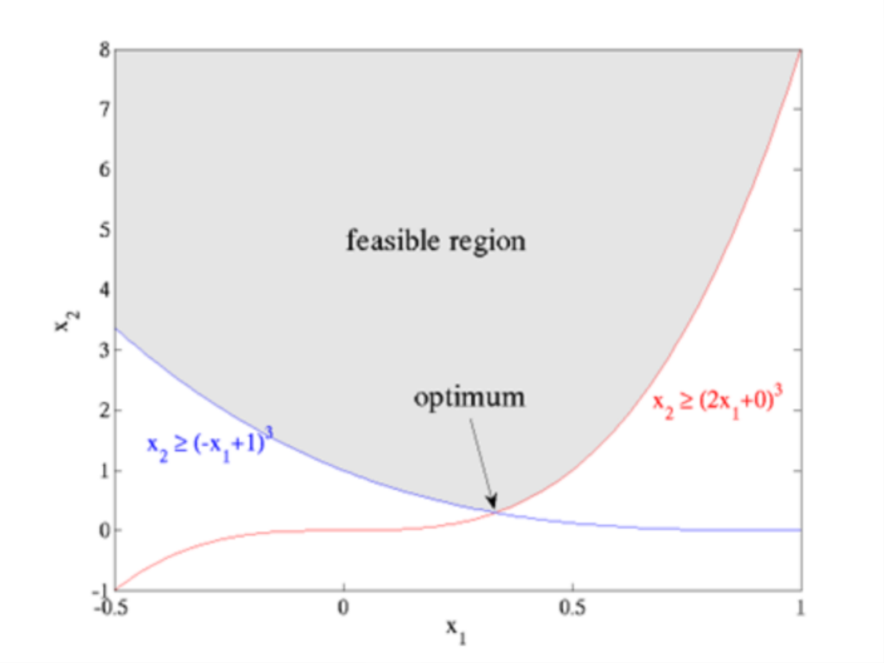
Glossary of Technical Terms

Bioptim

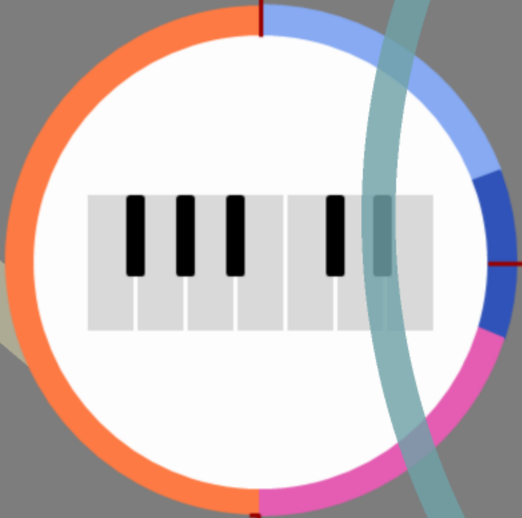
Biomechanical optimal control

`Bioptim` is an optimal control program (OCP) framework for biomechanics. It is based on the efficient biorbd biomechanics library and benefits from the powerful algorithmic diff provided by CasADi. It interfaces the robust `Ipopt` and the fast `Acados` solvers to suit all your needs for solving OCP in biomechanics.





OCP Structure/ Constraints



Pressed:

SUPERIMPOSE_MARKERS,

phase=Preparation, node=Node.ALL,

Finger tip and key marker (top)

Struck:

SUPERIMPOSE_MARKERS,

phase=Preparation, node=Node.START & Node.END,

Finger tip and key marker (top)

TRACK_MARKERS_VELOCITY,

phase=Key Descent,

Finge tip

SUPERIMPOSE_MARKERS,

phase= Key Descent, node=Node.END,

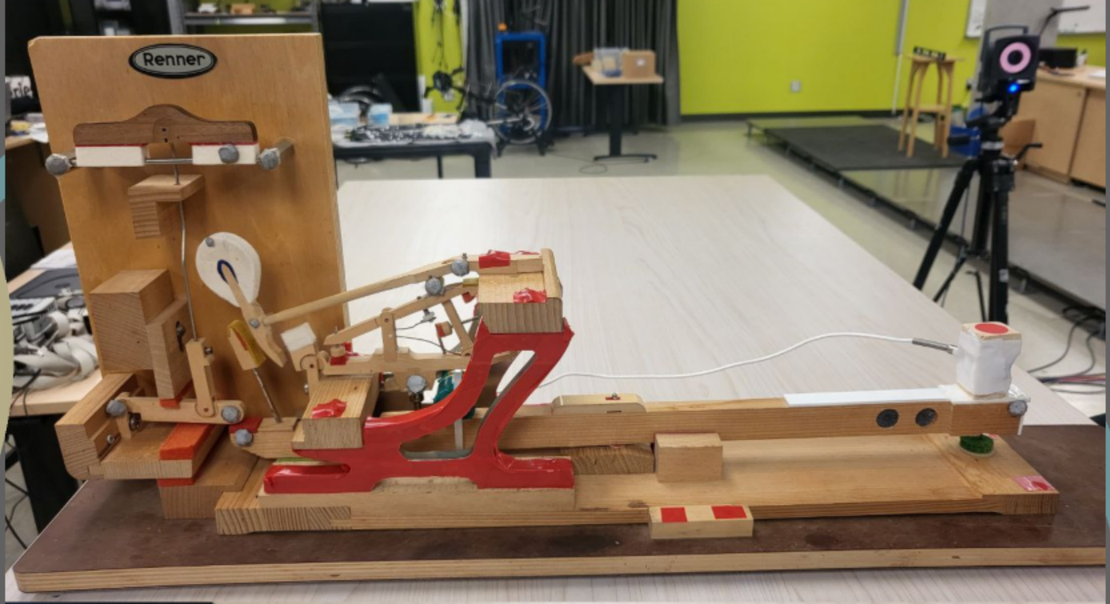
Finge tip and key marker (bottom)

TRACK_CONTACT_FORCES,

phase=Key Bed,

target=Force Profile,

Exp. Data



OCP Structure/ Constraints

Pressed:
vel_push_array = [0.0, -0.756, -1.120, -1.210, -0.873, -0.450, -0.058,] [m./s]
n_shooting = (30, 7, 9, 10, 10)
phase_time = (0.3, 0.024, 0.0605, 0.15, 0.15) [Sec]
Force_Profile = [57, 50, 43, 35, 26, 17, 8, 4, 0] [N]

Struck:
vel_push_array = [-1.244, -1.143, -0.652, -0.252, -0.196, -0.014,] [m./s]
n_shooting = (30, 6, 9, 10, 10)
phase_time = (0.3, 0.020, 0.0501, 0.15, 0.15) [Sec]
Force_Profile = [54, 47, 41, 35, 28, 18, 10, 4, 0] [N]

SUPERIMPOSE_MARKERS,

phase= Key Release (upward), node=Node.END,

Finger tip and Predefined marker (above the key)

SUPERIMPOSE_MARKERS,

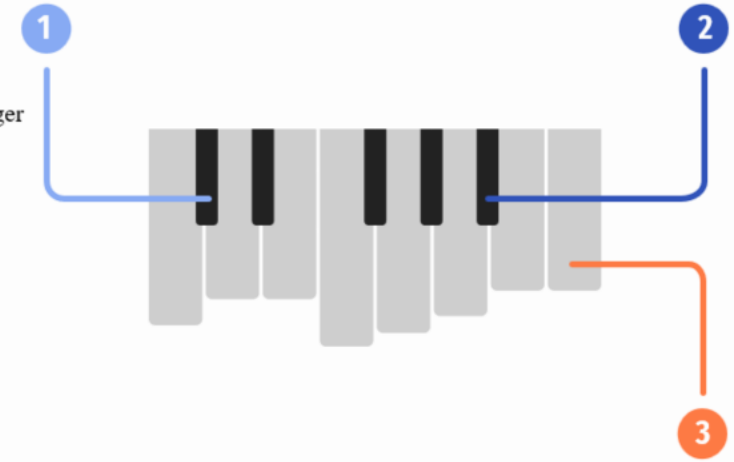
phase= Key Release node=Node.END,

Finger tip and key Marker (Top)

Minimization of torque

- Bates & Hewett (2016)
- Guo et al. (2021)
- Furuya & Altenmüller (2013)

OCP Structure/ Objectives



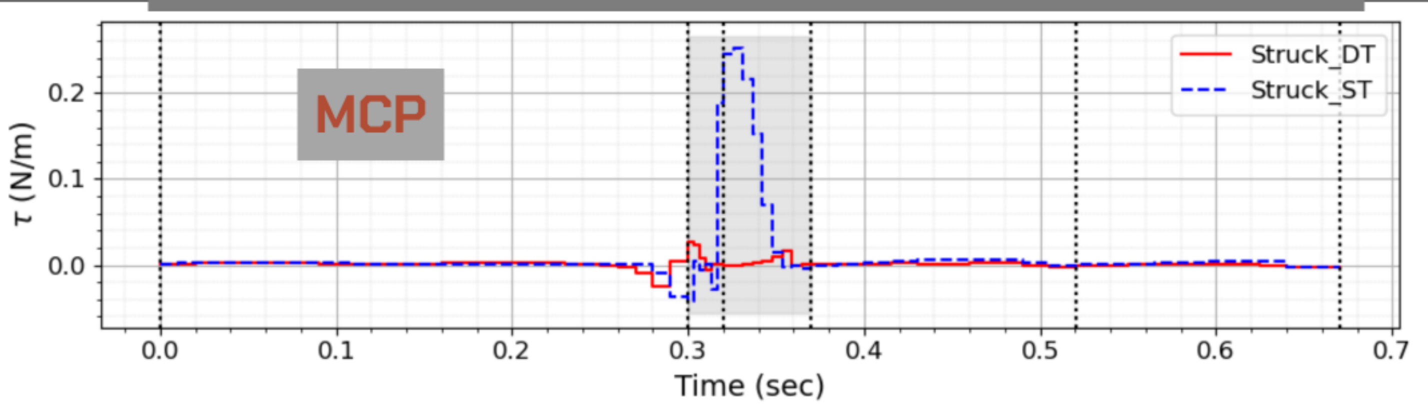
MINIMIZE_CONTROL,
key="tau",phase=all_phase,
weight=0.001,
index=all_dof_except_wrist_finger

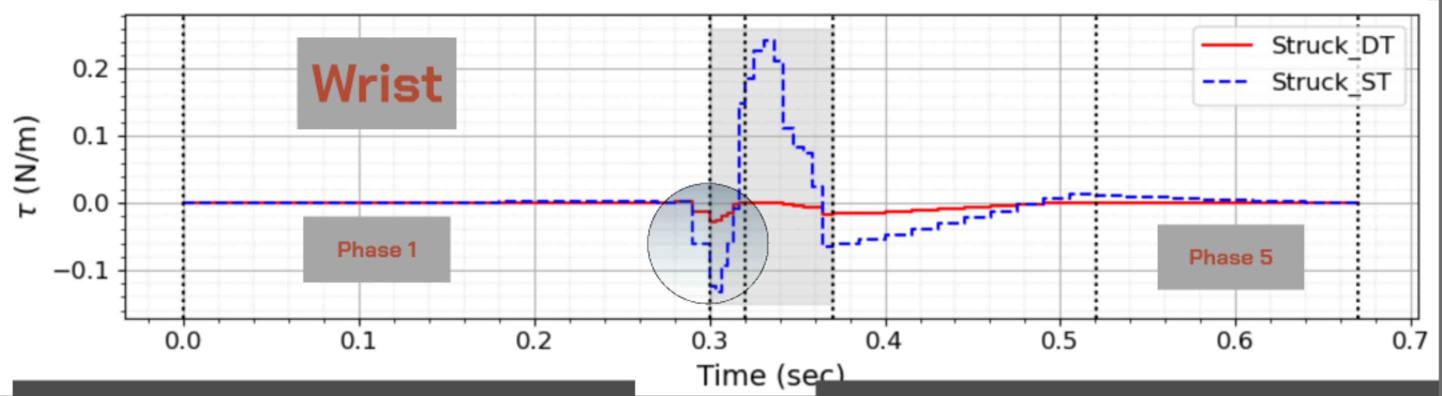
MINIMIZE_CONTROL,
key="tau", phase=all_phases,
weight=200,
index=dof_wrist_finger

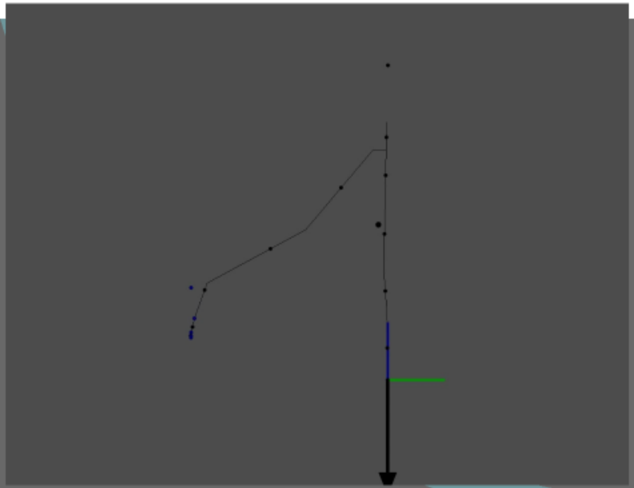
MINIMIZE_STATE,
key="qdot",phase=[0, 1],
weight=0.2,
index=dof_wrist

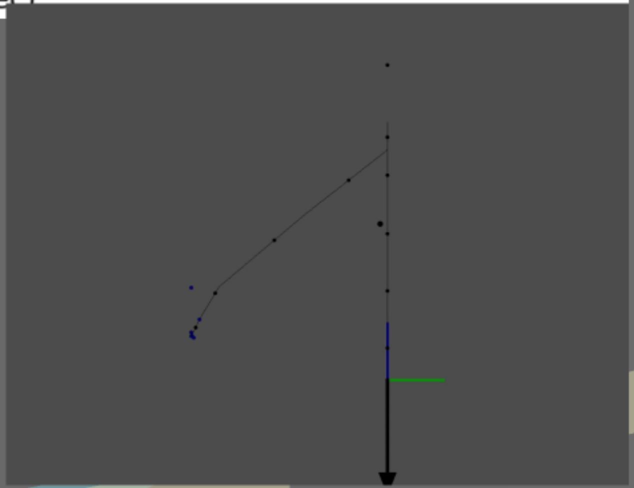
Results_Struck Touch

The study by Stefanyshyn et al. (2006) supports the significance of the torque-time graph's AUC, or impulse,in biomechanis, highlighting its role in predicting injuries.

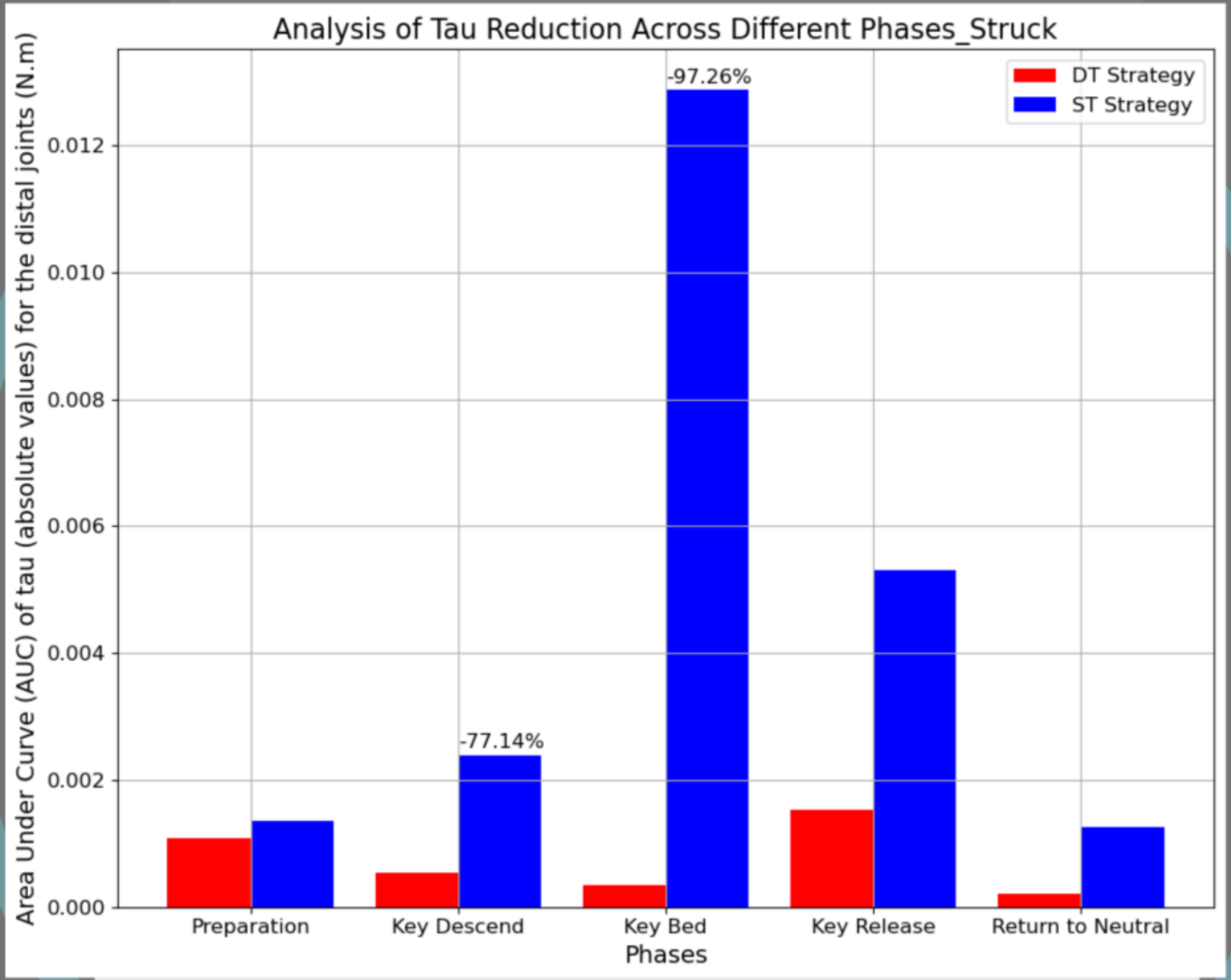








Result_Struck Touch (%)

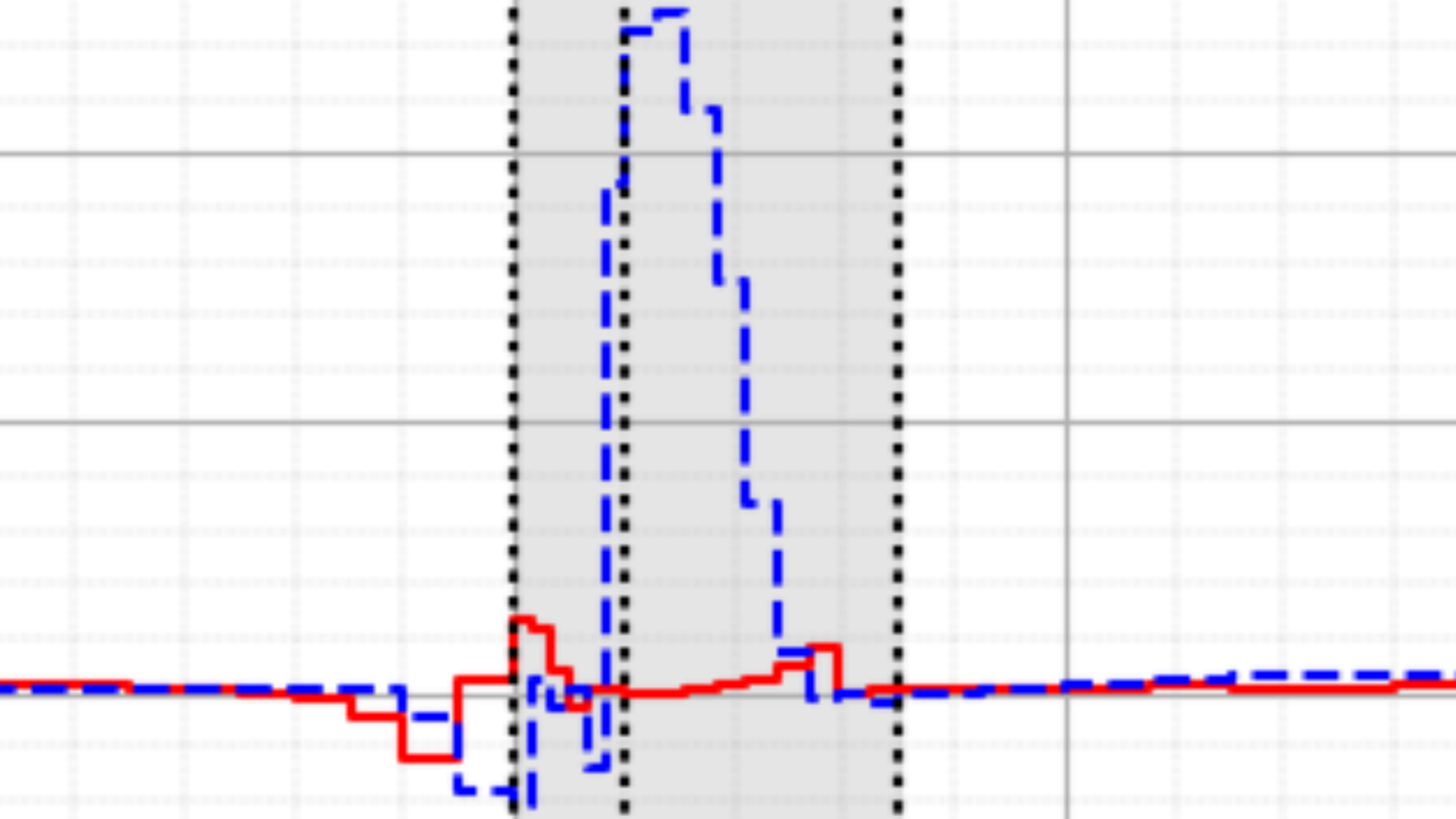


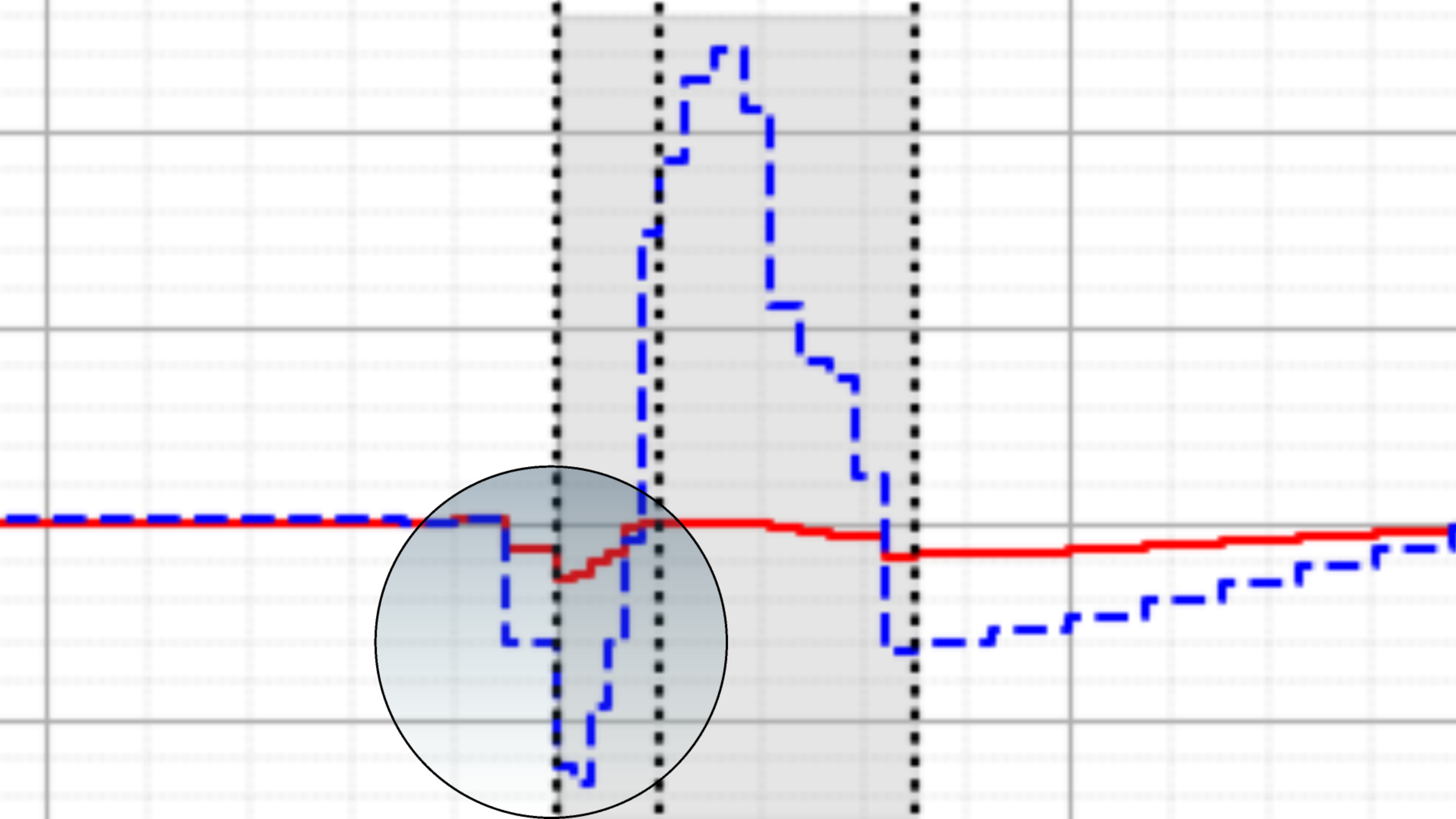
Using absolute values:

percentage_diff=
[(DT_absolute_Values– ST_absolute_Values) /(ST_absolute_Values)]×100 where:

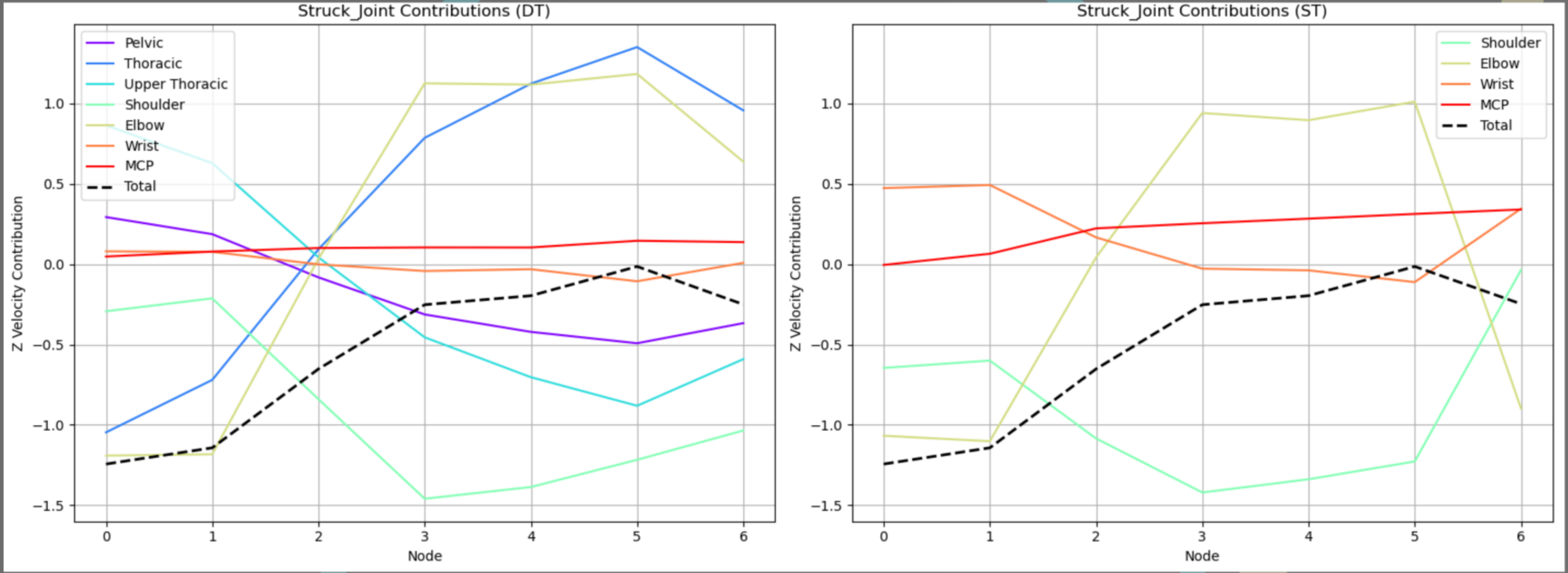
- **DT_absolute_Values is the sum of the AUC of the absolute tau values for the MCP and Wrist joints for DT strategy.**

- **ST_absolute_Values is the sum of the AUC of the absolute tau values for the MCP and Wrist joints for ST strategy.**

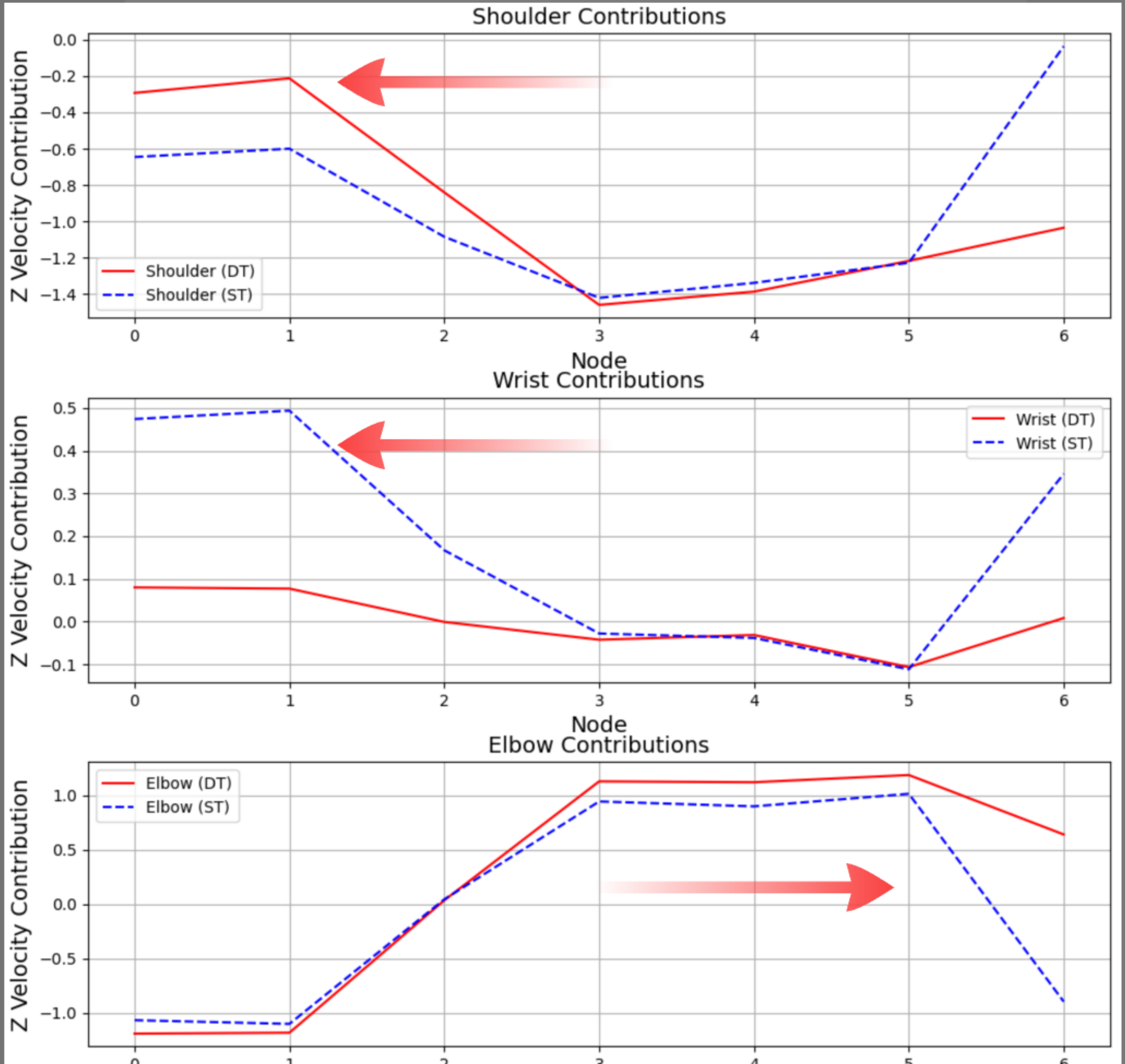




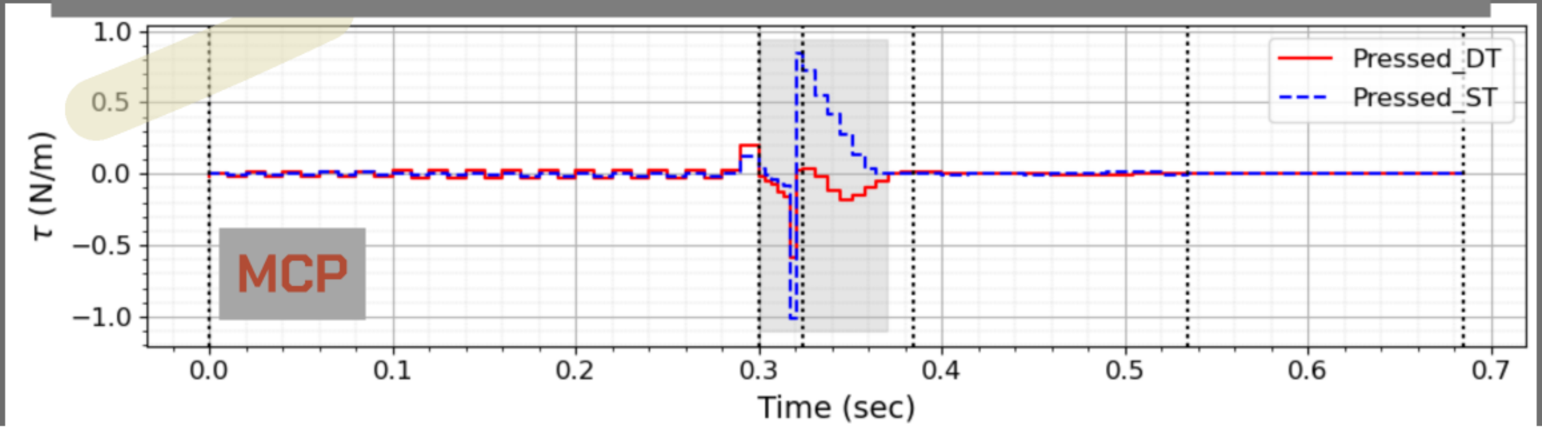
Discussion_Struck Touch_Phase1

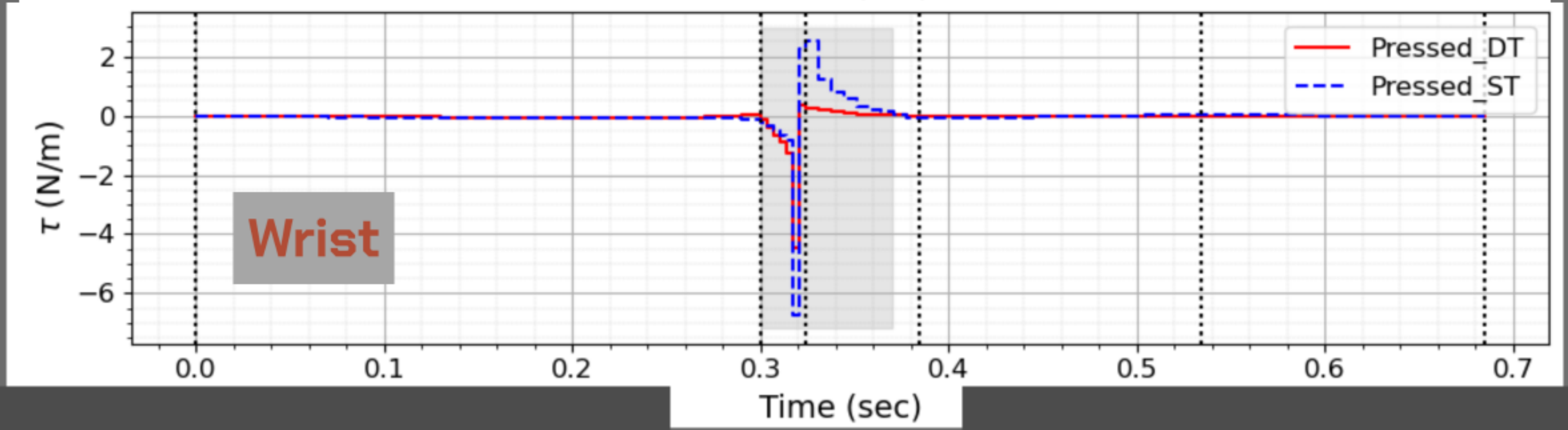


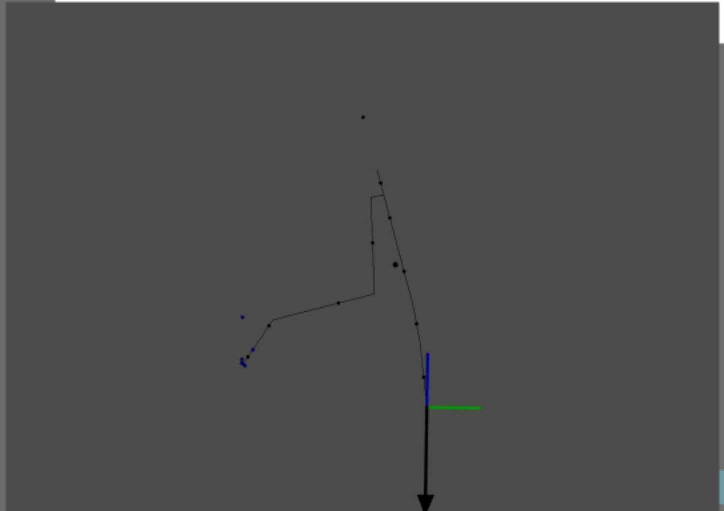
Discussion_Struck Touch_Phase1

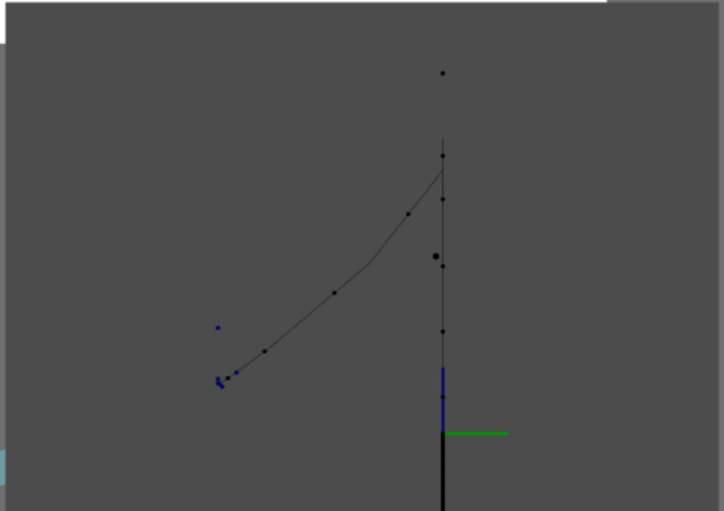


Results_Pressed Touch

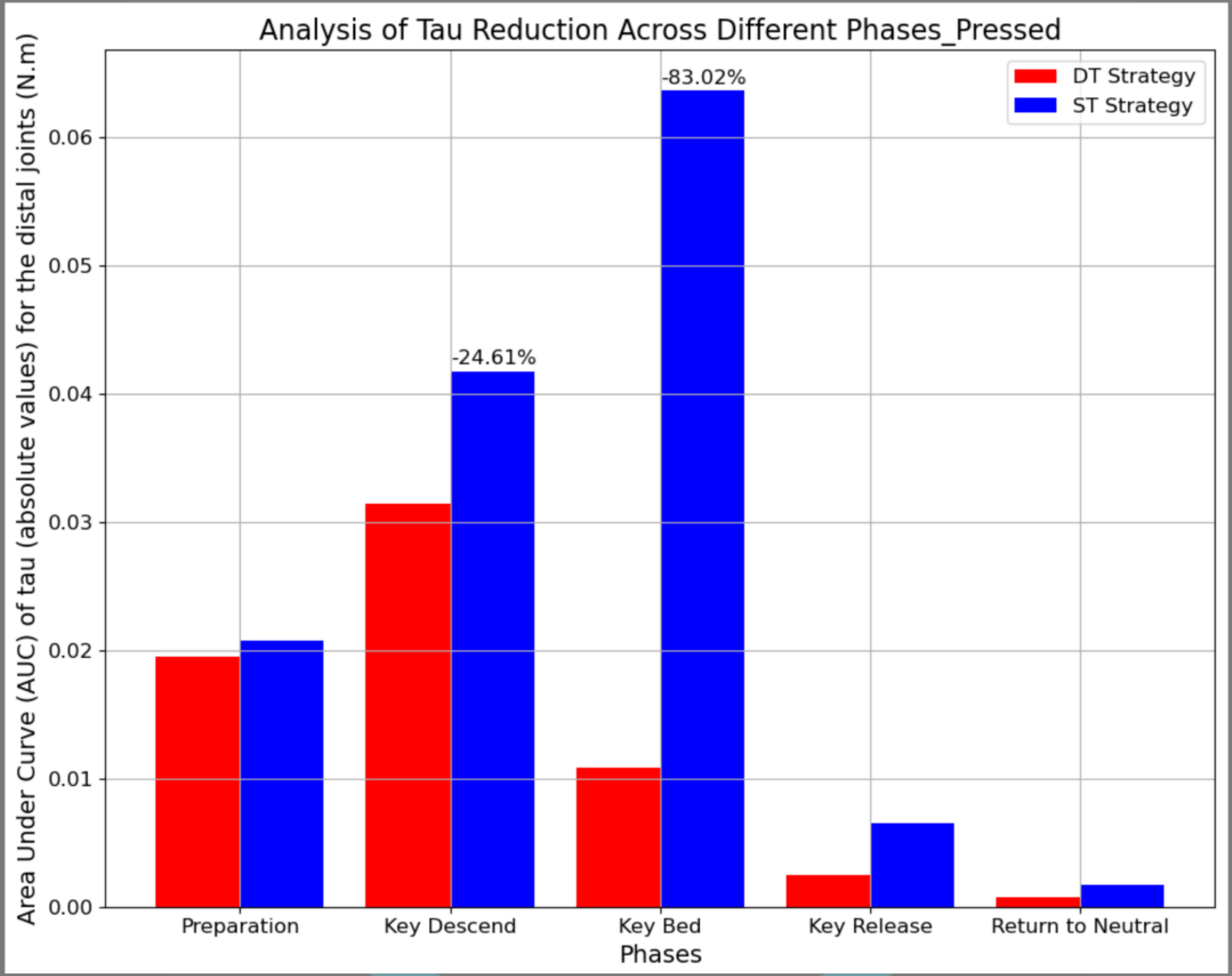


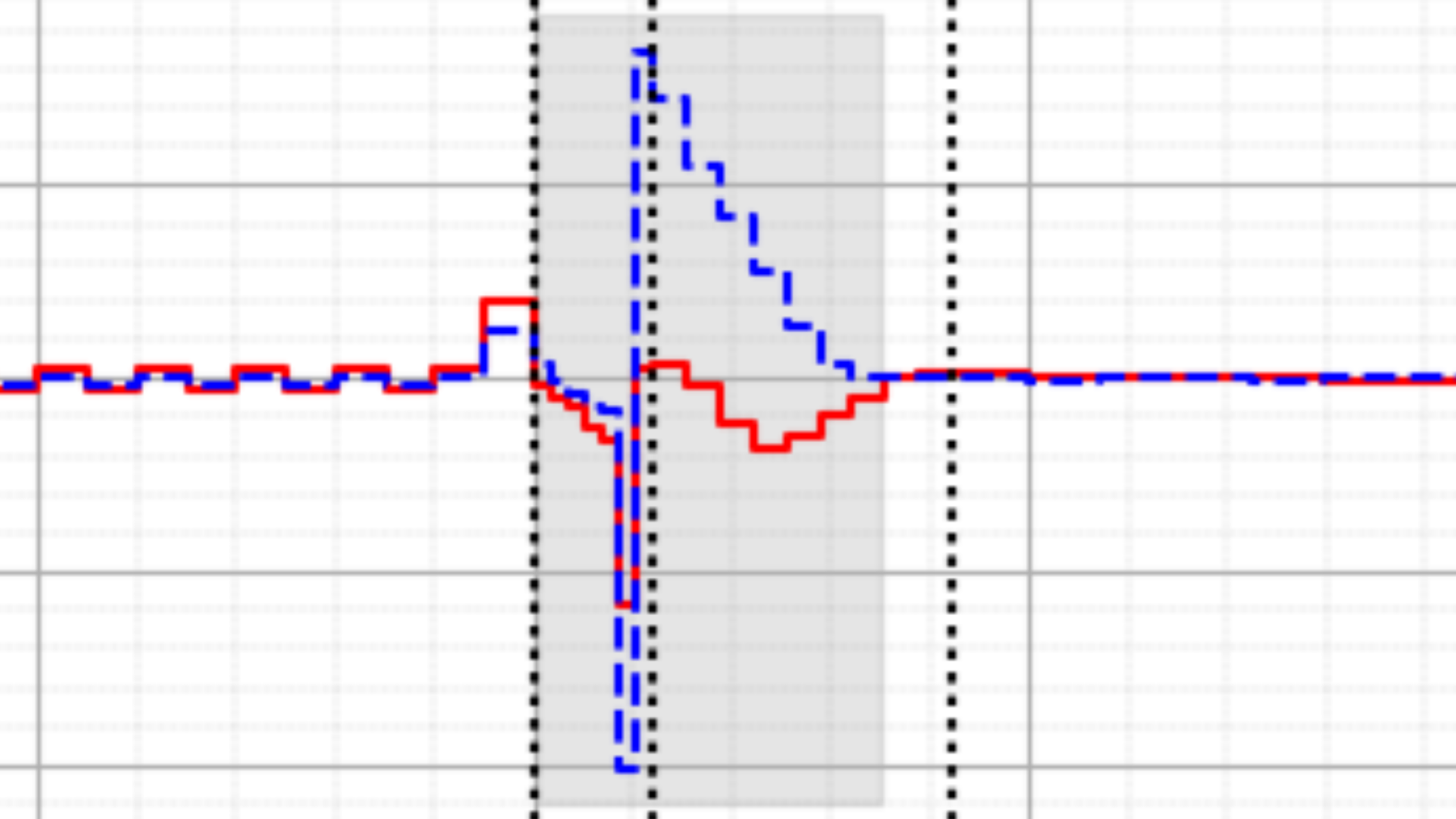


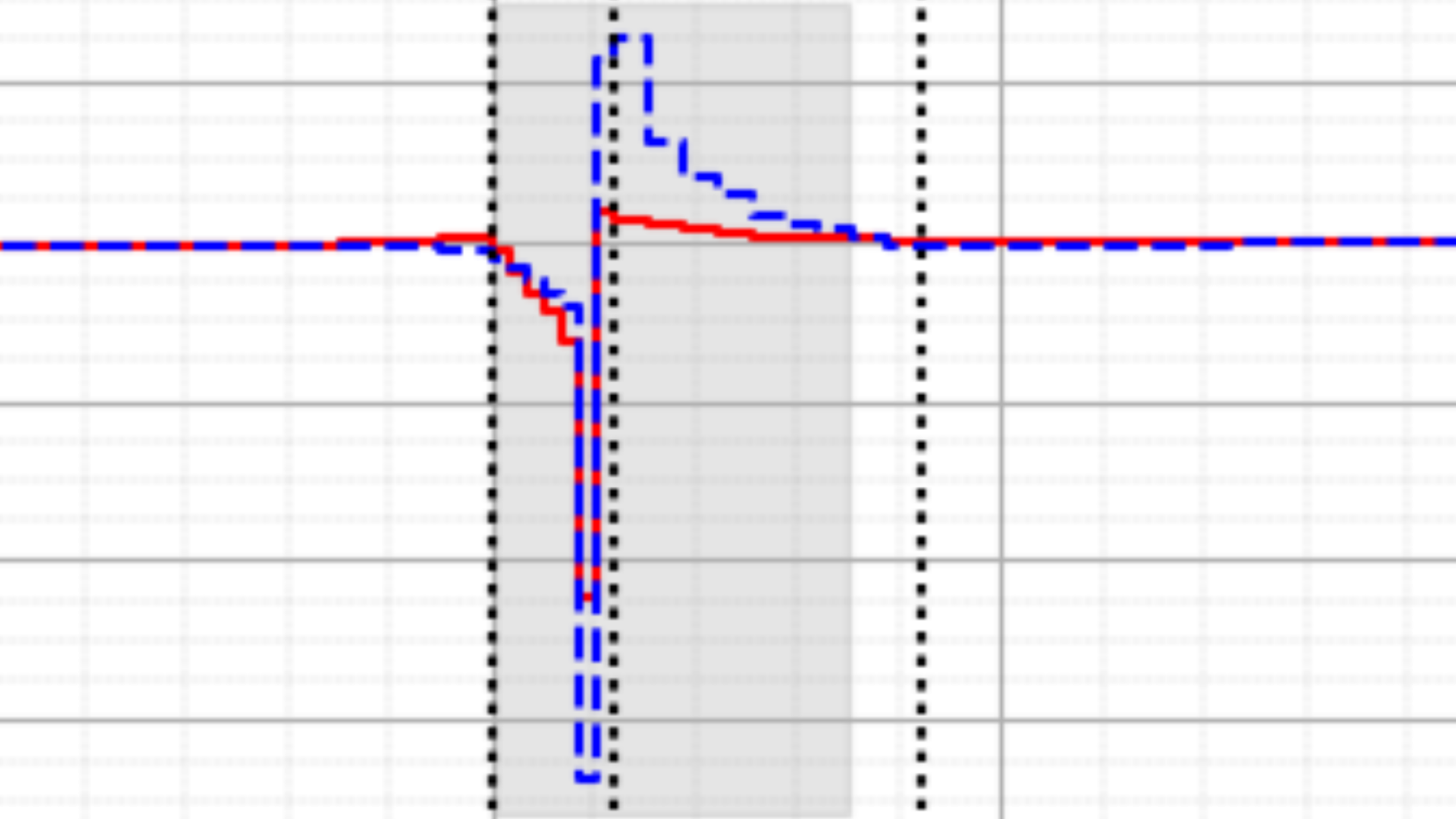




Result_Pressed Touch (%)



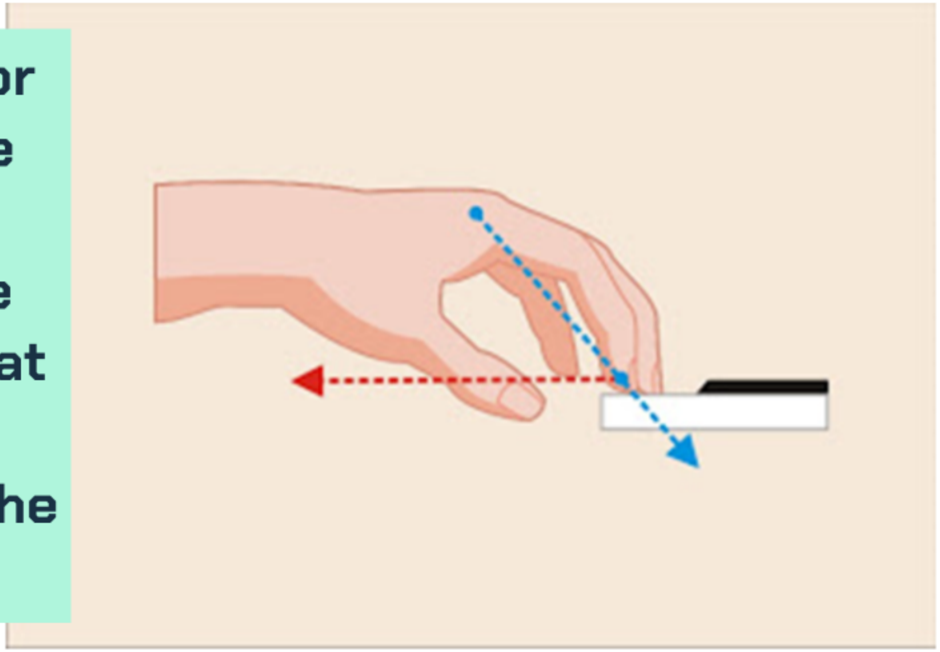




Consider the bottom-up model involving fingers, wrists, and piano keys, presented in a simplified, side-view format.

In Phases 1 and 2, the positions are certain **[the fingers should be in contact with the piano keys]**

The "line of attack" or "attack angle" in the context of piano playing refers to the angle and trajectory at which the fingers approach and strike the piano keys.



OVERUSE INJURIES AND PIANO TECHNIQUE:

A BIOMECHANICAL APPROACH

by

BRENDA G. WRISTEN, B.A., M.M.

A DISSERTATION

IN

FINE ARTS

Submitted to the Graduate Faculty
of Texas Tech University in
Partial Fulfillment of
the Requirements for
the Degree of

DOCTOR OF PHILOSOPHY

Approved

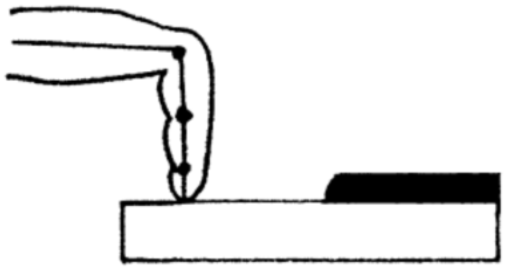
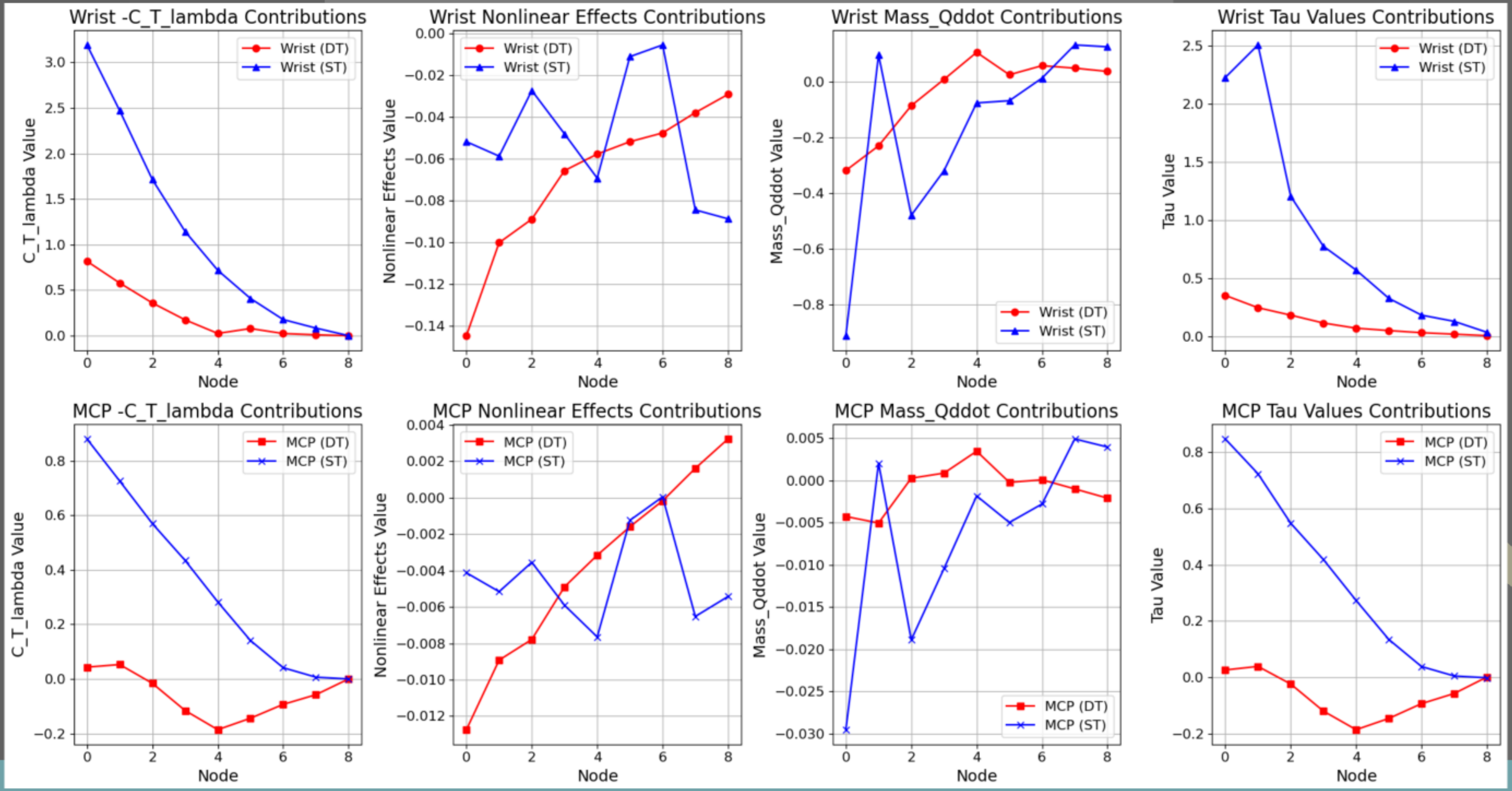


Figure 4.8. Optimum Position for Reduction of MCP Joint Force

Discussion_Pressed Touch_Phase2



C_T_lambda (Contact force contribution):

• Emphasize that C_T_lambda represents the contribution of the contact forces to the generalized forces acting on the model.

Nonlinear_Effects (Nonlinear effects contribution):

• Explain that nonlinear effects, such as Coriolis and centrifugal forces, arise due to the nonlinear nature of the model's dynamics. [depends on the configuration (positions) and velocities]

[how the motion of one body segment can affect the motion of other segments due to the coupling between their velocities and positions.]

Mass_Qddot:

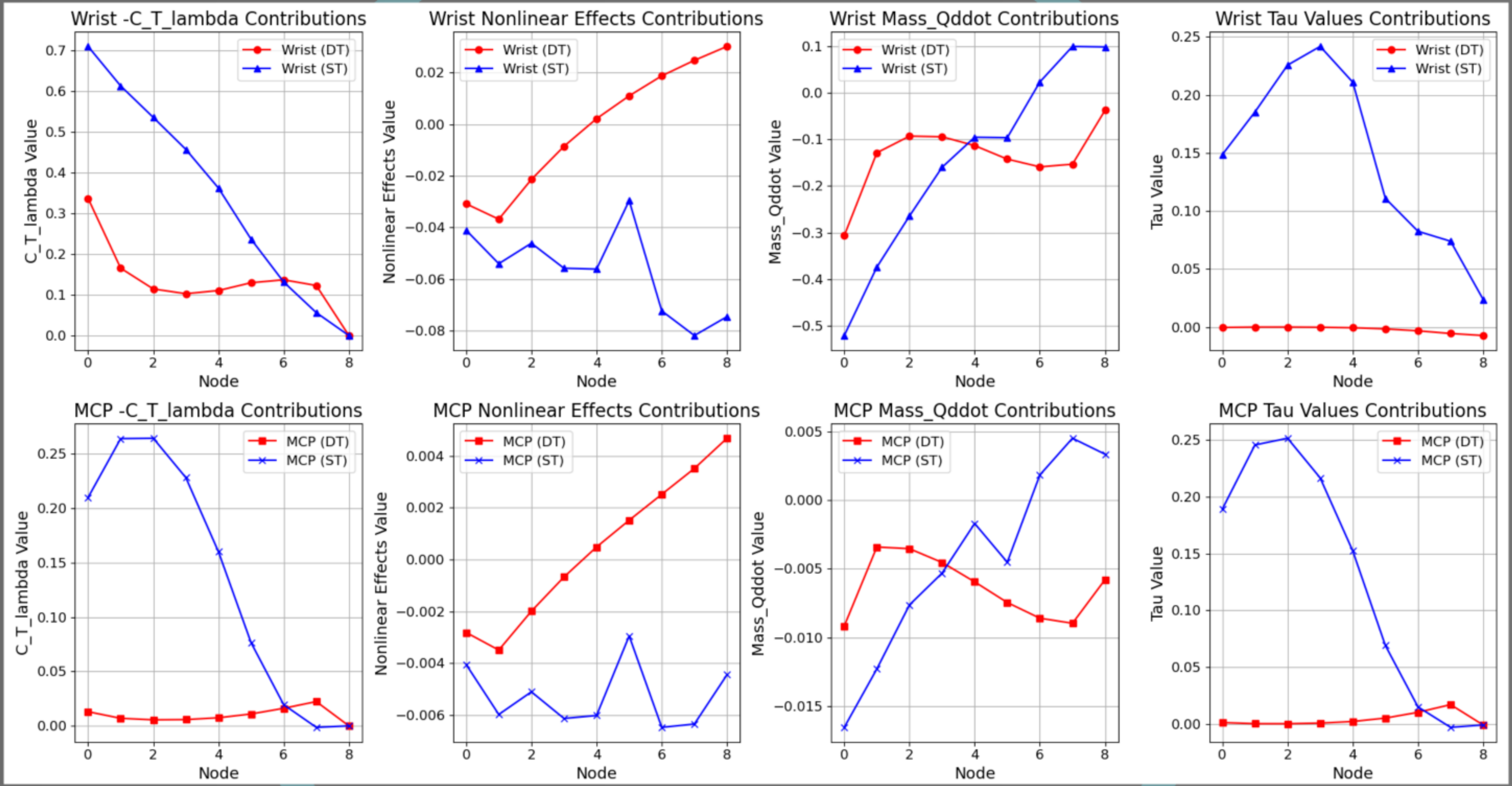
• Mass matrix (M) represents the inertial properties of the model and depends on the configuration (positions) of the model.

• Represents the inertial forces acting on the model.

Tau (Control torques):

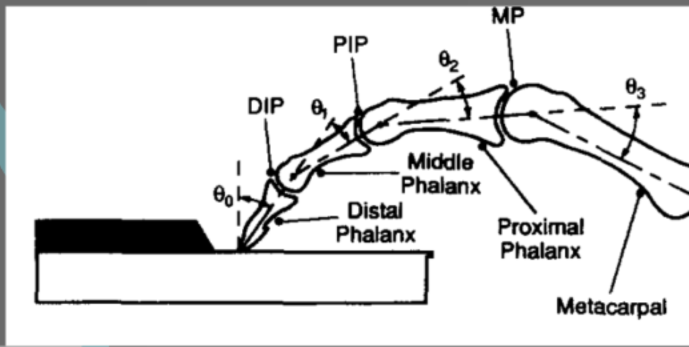
• Tau represents the control torques or forces applied to the model's joints.

Discussion_Struck Touch_Phase2



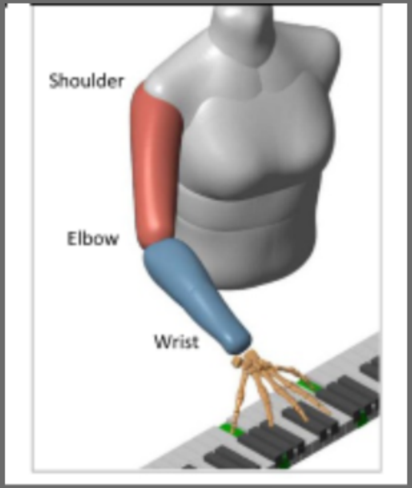
Critical analysis and Next steps

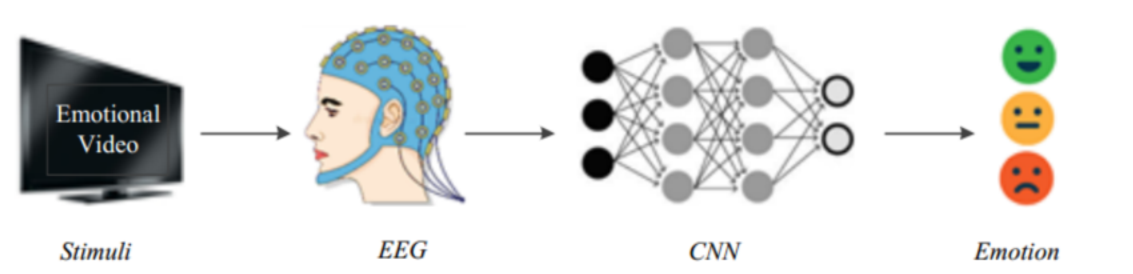
$$DJ = \sqrt{\frac{1}{2} \int_{t_1}^{t_2} \left(\frac{d^3x}{dt^3} \right)^2 dt \cdot \frac{D^5}{A^2}}$$



The dimensionless jerk (DJ) is a measure of movement smoothness that is independent of movement duration and amplitude.

x is position/angle
t is time
t1 and t2 are the start and end times of the movement
A is movement amplitude
D=t2−t1 is movement duration

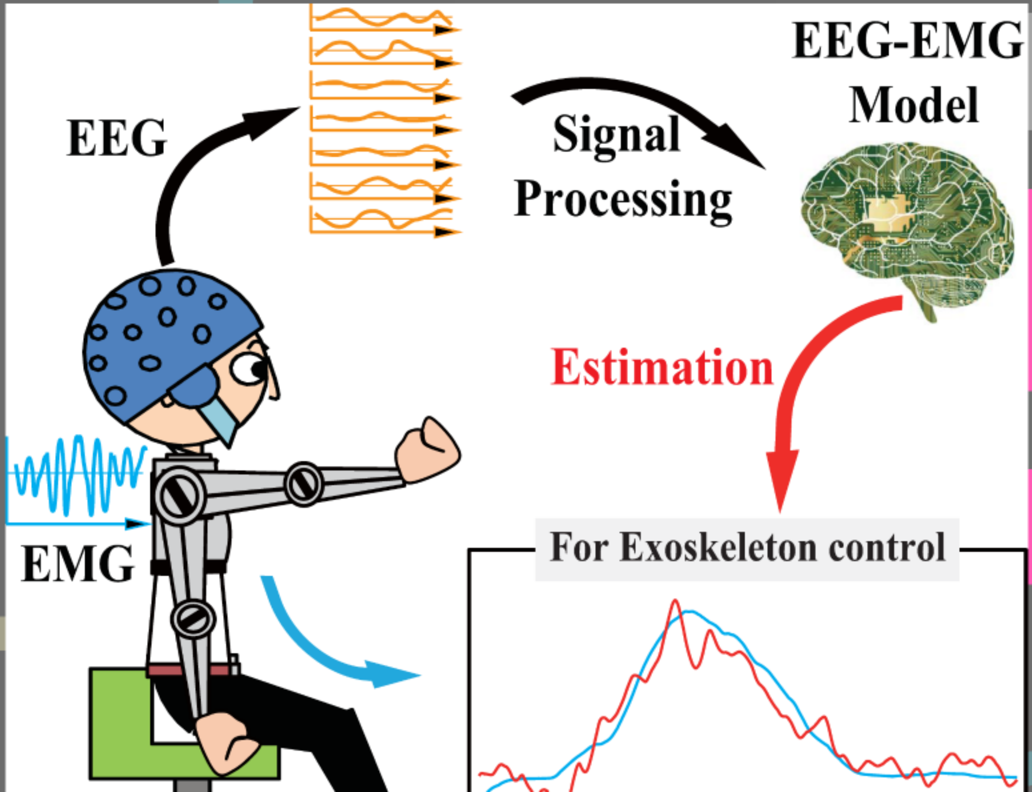




Emotion Recognition from EEG signal using CNN

The challenge is to keep pianists healthy without compromising their art.

Emotion/Expression

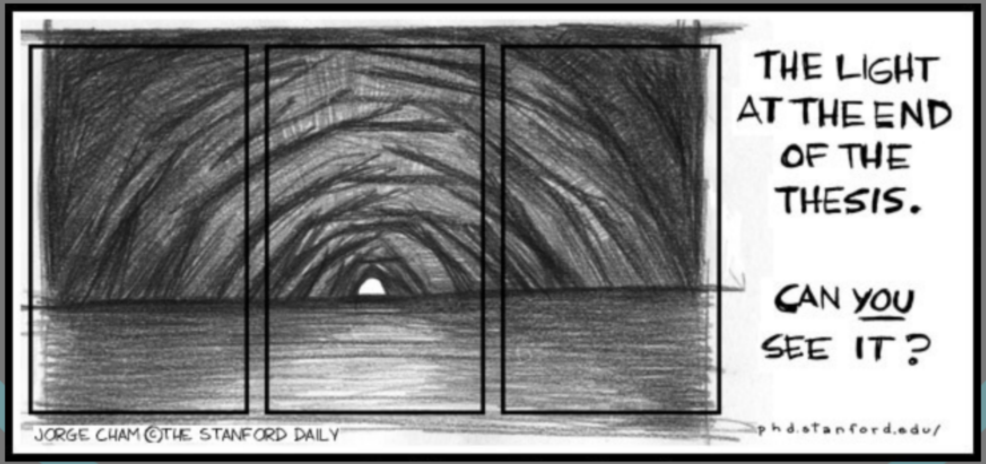


EEG-Based EMG Estimation

Joint Power
Mechanical Work

Muscle Synergy


Thanks!


THE LIGHT AT THE END OF THE THESIS.
CAN YOU SEE IT?
JORGE CHAM ©THE STANFORD DAILY
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Optimization of pianists' whole-body gestures through the integration of experimental and simulation research approaches

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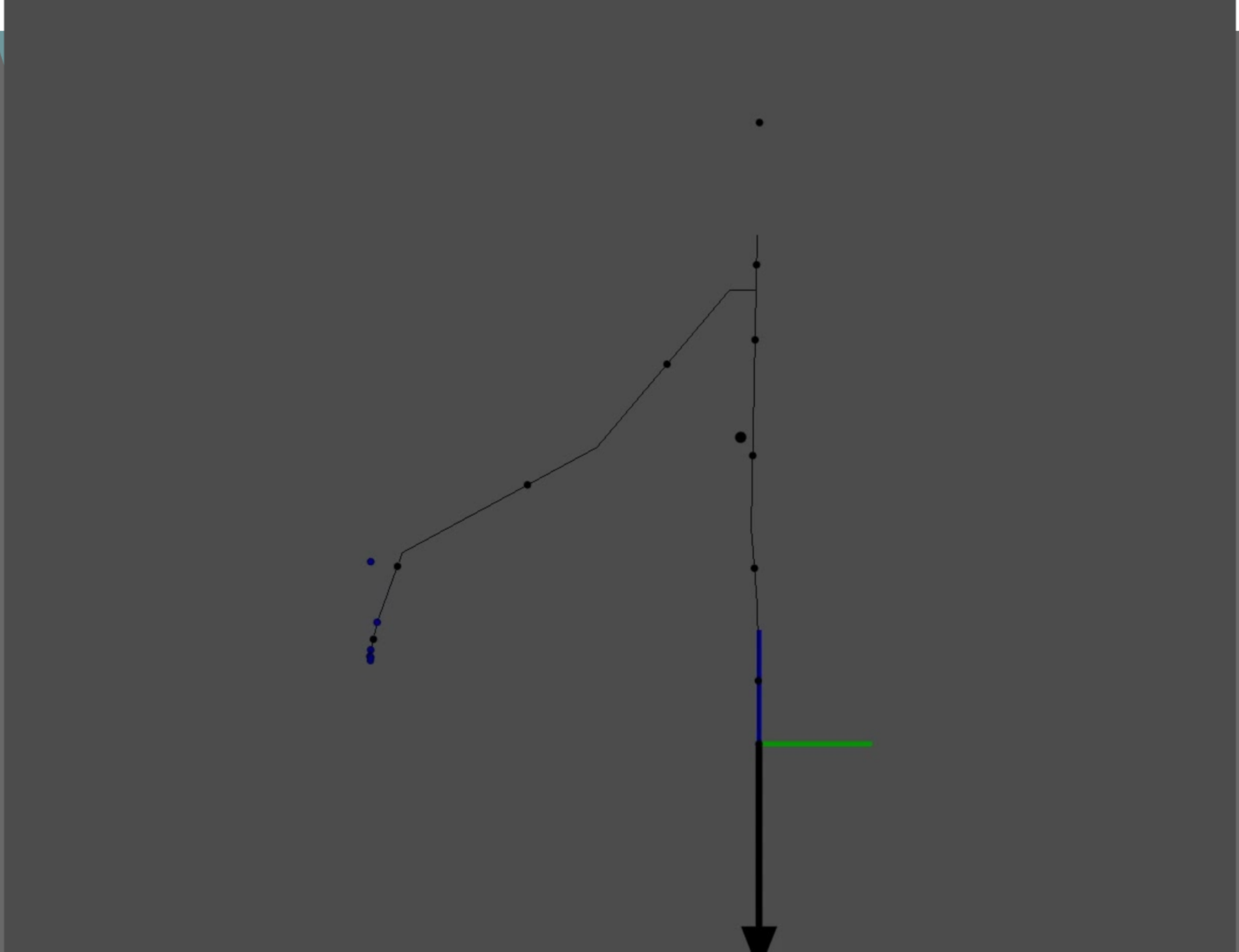

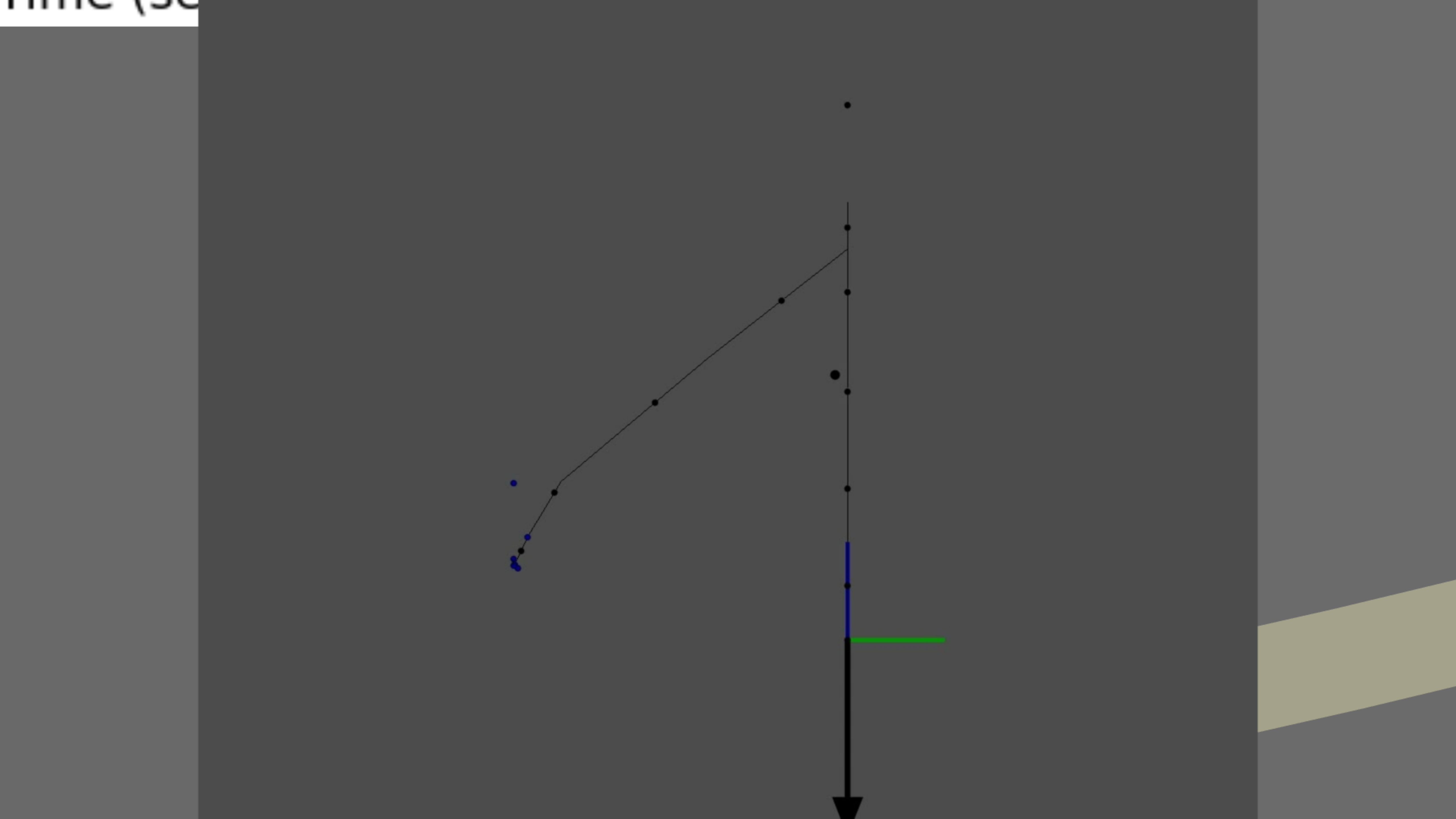

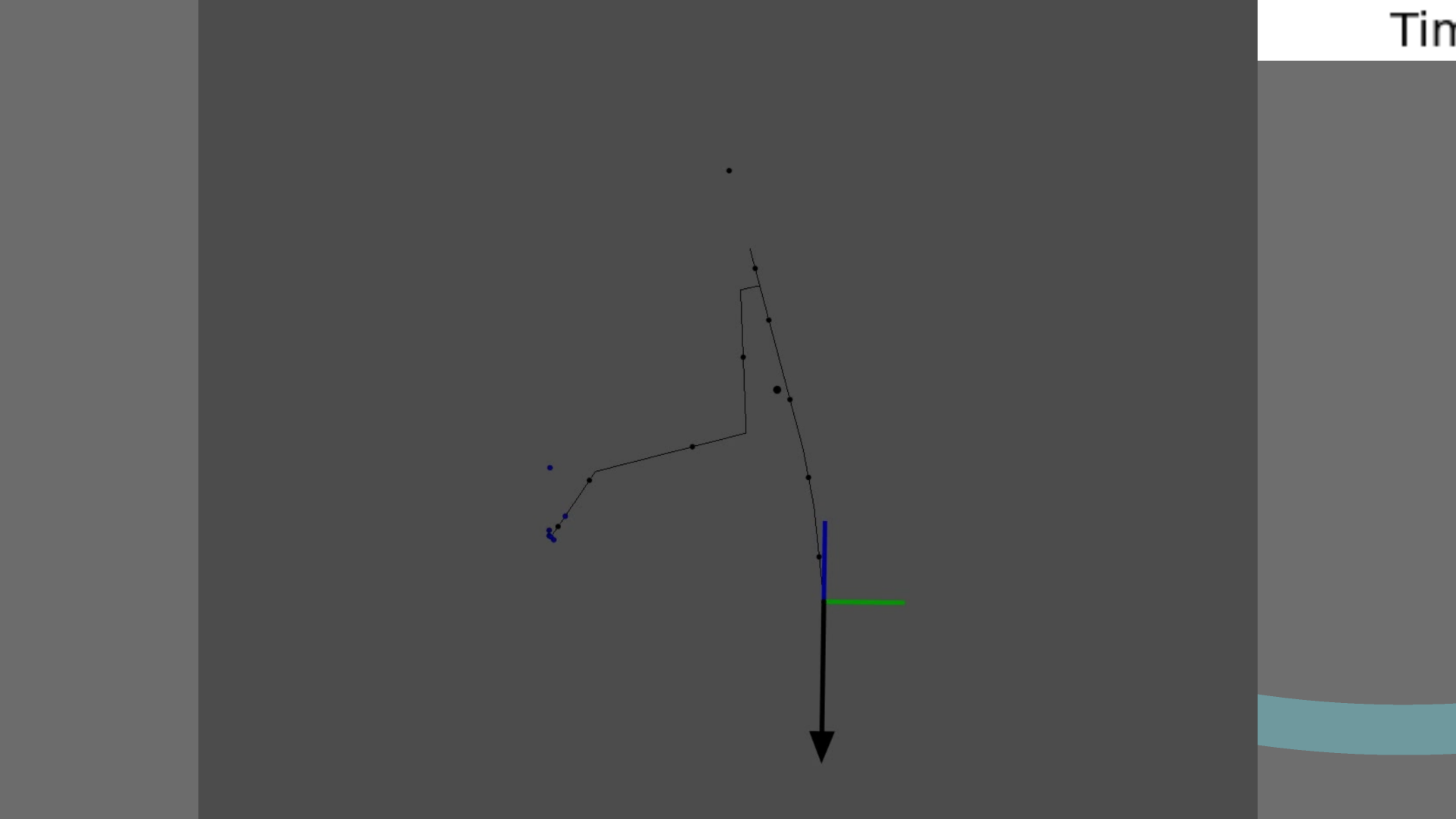
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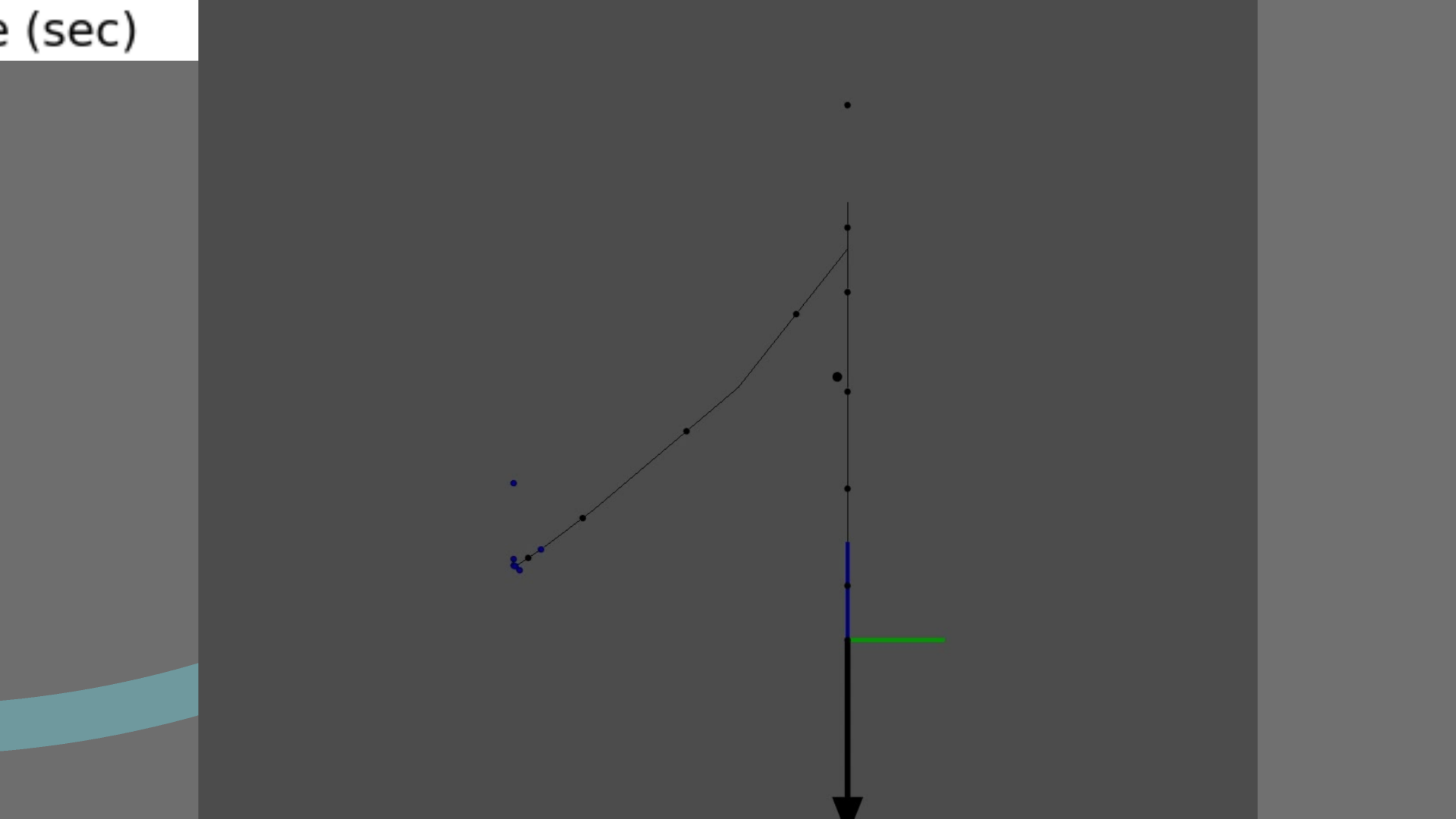
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Discussion_Struck Touch

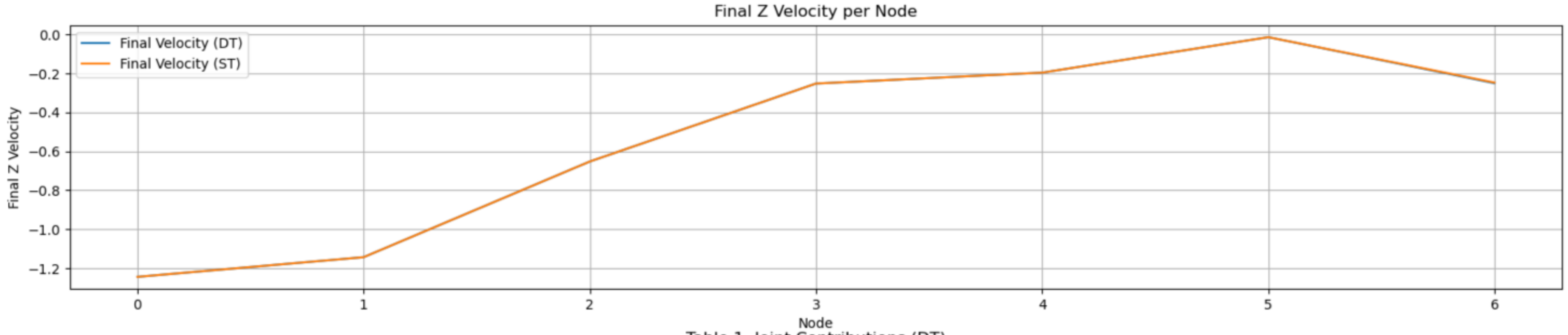

Table 1: Joint Contributions (DT)

Node	Pelvic	Thoracic	Upper Thoracic	Shoulder	Elbow	Wrist	MCP	Total
0	0.29	-1.05	0.87	-0.29	-1.19	0.08	0.05	-1.24
1	0.19	-0.72	0.63	-0.21	-1.18	0.08	0.08	-1.14
2	-0.08	0.09	0.04	-0.84	0.03	-0.0	0.1	-0.65
3	-0.31	0.79	-0.45	-1.46	1.13	-0.04	0.1	-0.25
4	-0.42	1.12	-0.7	-1.39	1.12	-0.03	0.1	-0.2
5	-0.49	1.35	-0.88	-1.22	1.18	-0.11	0.15	-0.01
6	-0.37	0.96	-0.59	-1.04	0.64	0.01	0.14	-0.25

Table 2: Joint Contributions (ST)

Node	Shoulder	Elbow	Wrist	MCP	Total
0	-0.65	-1.07	0.47	-0.0	-1.24
1	-0.6	-1.1	0.49	0.07	-1.14
2	-1.08	0.04	0.17	0.22	-0.65
3	-1.42	0.94	-0.03	0.26	-0.25
4	-1.34	0.9	-0.04	0.28	-0.2
5	-1.23	1.01	-0.11	0.31	-0.01
6	-0.04	-0.9	0.35	0.34	-0.25

Discussion_Pressed Touch

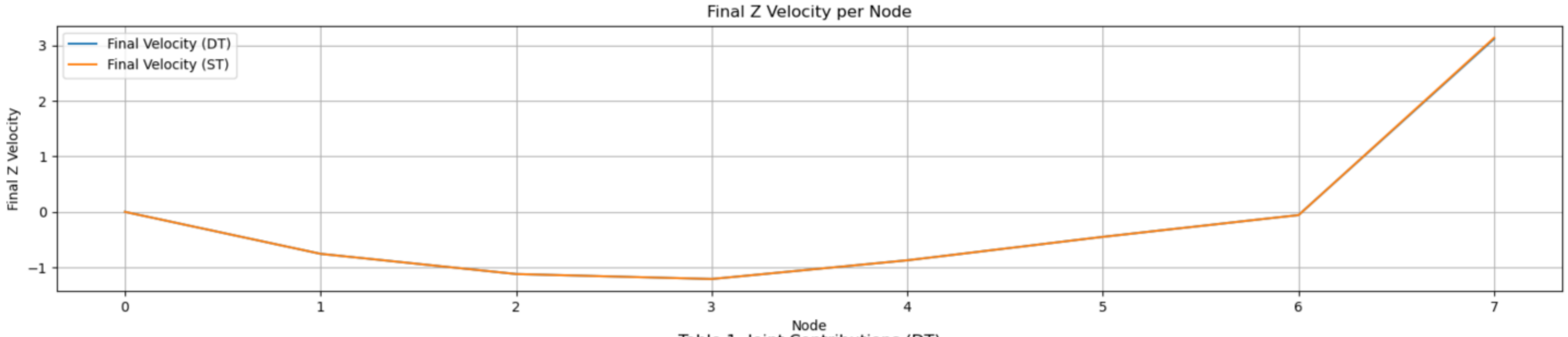

Table 1: Joint Contributions (DT)

Node	Pelvic	Thoracic	Upper Thoracic	Shoulder	Elbow	Wrist	MCP	Total
0	-0.07	0.22	-0.14	0.65	0.24	-1.41	0.51	0.0
1	0.25	-0.64	0.47	1.37	-0.59	-1.13	-0.49	-0.76
2	0.45	-1.46	1.18	1.25	-1.36	-0.73	-0.45	-1.12
3	0.38	-1.46	1.33	0.92	-1.34	-0.63	-0.4	-1.21
4	0.3	-1.35	1.36	1.0	-1.31	-0.5	-0.36	-0.87
5	0.06	-1.04	1.4	0.8	-1.29	-0.06	-0.32	-0.45
6	-0.17	-0.75	1.47	0.7	-1.47	0.45	-0.29	-0.06
7	-0.85	1.47	-0.16	0.63	1.48	0.24	0.31	3.12

Table 2: Joint Contributions (ST)

Node	Shoulder	Elbow	Wrist	MCP	Total
0	0.56	-1.03	0.37	0.1	-0.0
1	0.45	-0.26	-0.31	-0.64	-0.76
2	0.4	0.53	-1.43	-0.62	-1.12
3	0.64	0.49	-1.75	-0.59	-1.21
4	1.3	0.05	-1.67	-0.55	-0.87
5	1.47	-0.05	-1.37	-0.51	-0.45
6	0.75	0.98	-1.31	-0.47	-0.06
7	0.32	0.78	1.56	0.48	3.14

Discussion_Struck Touch

MCP Metrics for DT and ST Scenarios

Metric	Node 1	Node 2	Node 3	Node 4	Node 5	Node 6	Node 7	Node 8	Node 9
-C_T_lambda (DT)	0.013	0.0069	0.0055	0.0058	0.0075	0.0109	0.0162	0.0223	-0.0
-C_T_lambda (ST)	0.2099	0.264	0.2644	0.2281	0.16	0.0764	0.0195	-0.0014	0.0

Metric	Node 1	Node 2	Node 3	Node 4	Node 5	Node 6	Node 7	Node 8	Node 9
NL Effects (DT)	-0.0028	-0.0035	-0.002	-0.0007	0.0005	0.0015	0.0025	0.0035	0.0047
NL Effects (ST)	-0.004	-0.006	-0.0051	-0.0061	-0.006	-0.0029	-0.0065	-0.0063	-0.0044

Metric	Node 1	Node 2	Node 3	Node 4	Node 5	Node 6	Node 7	Node 8	Node 9
Mass Qddot (DT)	-0.0092	-0.0034	-0.0035	-0.0045	-0.006	-0.0075	-0.0086	-0.009	-0.0058
Mass Qddot (ST)	-0.0166	-0.0123	-0.0076	-0.0053	-0.0017	-0.0045	0.0019	0.0045	0.0034

Metric	Node 1	Node 2	Node 3	Node 4	Node 5	Node 6	Node 7	Node 8	Node 9
Tau (DT)	0.001	0.0	0.0	0.0006	0.002	0.005	0.0101	0.0169	-0.0011
Tau (ST)	0.1893	0.2457	0.2516	0.2167	0.1523	0.069	0.0148	-0.0032	-0.0011

Wrist Metrics for DT and ST Scenarios

Metric	Node 1	Node 2	Node 3	Node 4	Node 5	Node 6	Node 7	Node 8	Node 9
-C_T_lambda (DT)	0.3371	0.1655	0.1145	0.1027	0.1106	0.1298	0.137	0.1229	-0.0
-C_T_lambda (ST)	0.7105	0.6134	0.5361	0.4574	0.3623	0.2368	0.1316	0.0562	0.0

Metric	Node 1	Node 2	Node 3	Node 4	Node 5	Node 6	Node 7	Node 8	Node 9
NL Effects (DT)	-0.0308	-0.0368	-0.0214	-0.0085	0.0022	0.011	0.0188	0.0248	0.0302
NL Effects (ST)	-0.041	-0.054	-0.0461	-0.0558	-0.0561	-0.0296	-0.0723	-0.0818	-0.0745

Metric	Node 1	Node 2	Node 3	Node 4	Node 5	Node 6	Node 7	Node 8	Node 9
Mass Qddot (DT)	-0.3065	-0.1286	-0.093	-0.0943	-0.1133	-0.1423	-0.1589	-0.1531	-0.0374
Mass Qddot (ST)	-0.5209	-0.374	-0.2644	-0.1599	-0.0953	-0.0963	0.0233	0.0996	0.0984

Discussion_Pressed Touch

MCP Metrics for DT and ST Scenarios

Metric	Node 1	Node 2	Node 3	Node 4	Node 5	Node 6	Node 7	Node 8	Node 9
-C_T_lambda (DT)	0.0433	0.0529	-0.0161	-0.1157	-0.1859	-0.1439	-0.0932	-0.0578	-0.0
-C_T_lambda (ST)	0.8797	0.7255	0.5694	0.4345	0.2824	0.1407	0.0412	0.0065	-0.0

Metric	Node 1	Node 2	Node 3	Node 4	Node 5	Node 6	Node 7	Node 8	Node 9
NL Effects (DT)	-0.0127	-0.0089	-0.0078	-0.0049	-0.0032	-0.0016	-0.0002	0.0016	0.0032
NL Effects (ST)	-0.0041	-0.0052	-0.0036	-0.0059	-0.0077	-0.0012	0.0	-0.0065	-0.0054

Metric	Node 1	Node 2	Node 3	Node 4	Node 5	Node 6	Node 7	Node 8	Node 9
Mass Qddot (DT)	-0.0043	-0.0051	0.0003	0.0009	0.0035	-0.0002	0.0001	-0.001	-0.0021
Mass Qddot (ST)	-0.0295	0.002	-0.0189	-0.0105	-0.0018	-0.005	-0.0028	0.0049	0.004

Metric	Node 1	Node 2	Node 3	Node 4	Node 5	Node 6	Node 7	Node 8	Node 9
Tau (DT)	0.0263	0.0389	-0.0236	-0.1197	-0.1857	-0.1458	-0.0933	-0.0572	0.0011
Tau (ST)	0.846	0.7224	0.547	0.4181	0.2729	0.1345	0.0384	0.0049	-0.0015

Wrist Metrics for DT and ST Scenarios

Metric	Node 1	Node 2	Node 3	Node 4	Node 5	Node 6	Node 7	Node 8	Node 9
-C_T_lambda (DT)	0.8166	0.578	0.3588	0.1737	0.0244	0.0781	0.0231	0.0095	-0.0
-C_T_lambda (ST)	3.191	2.4707	1.7132	1.1438	0.7173	0.4082	0.1768	0.0831	-0.0

Metric	Node 1	Node 2	Node 3	Node 4	Node 5	Node 6	Node 7	Node 8	Node 9
NL Effects (DT)	-0.1446	-0.1001	-0.0889	-0.0657	-0.0578	-0.0518	-0.0477	-0.0379	-0.0292
NL Effects (ST)	-0.0519	-0.0588	-0.0274	-0.0481	-0.0693	-0.0112	-0.0056	-0.0845	-0.0887

Metric	Node 1	Node 2	Node 3	Node 4	Node 5	Node 6	Node 7	Node 8	Node 9
Mass Qddot (DT)	-0.3182	-0.2297	-0.0857	0.0084	0.1055	0.0252	0.0578	0.0489	0.037
Mass Qddot (ST)	-0.9103	0.0968	-0.4788	-0.3191	-0.0758	-0.0679	0.0131	0.1321	0.1254

Metric	Node 1	Node 2	Node 3	Node 4	Node 5	Node 6	Node 7	Node 8	Node 9
Tau (DT)	0.3539	0.2482	0.1843	0.1165	0.0721	0.0515	0.0333	0.0205	0.0078
Tau (ST)	2.2289	2.5087	1.207	0.7765	0.5722	0.3291	0.1844	0.1307	0.0367

ORIGINAL RESEARCH

Wrist Positioning and Muscle Activities in the Wrist Extensor and Flexor During Piano Playing

Naoki Oikawa [a,b,*], Sadako Tsubota [c], Takako Chikenji [a],
Gyoku Chin [a,d], Mitsuhiro Aoki [e]

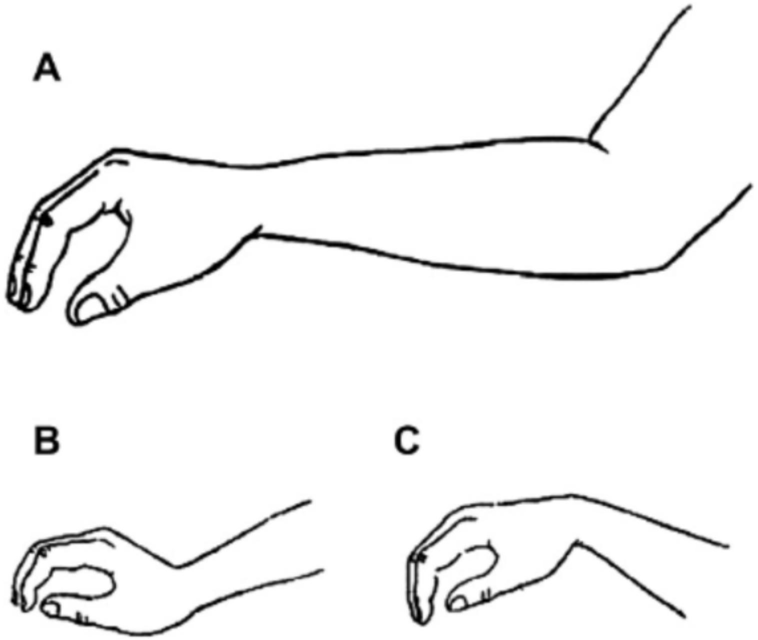

Figure 1 The recommended and wrong positions of the wrist during piano playing. Wrist positions during piano playing are presented based on a textbook for teaching piano techniques. The recommended position is (A) neutral; wrong positions are (B) dorsi flexion and (C) palmar flexion. We obtained permission to use the above illustrations from the publishing company (Ongaku-no Tomo Co., Tokyo, Japan).