Slip-Related Muscle Synergy during Human Walking

HAN UL YOON, Ph.D
and PILWON HUR, Ph.D

HUman Rehabilitation Group
TEXAS A&M UNIVERSITY

Outline

- Muscle synergy
- Research questions
- Method
- Results
- Discussion

Muscle synergy - Existing findings

Let's start with some quotations:

- "The brain does not control individual muscles independently but unites them in groups; namely, there are likely to be fewer control variables than muscles." – Hughlings Jackson

- "Muscle synergy exists and works as a neural strategy of simplifying the control of multiple muscles" – Nikolai Bernstein

- "Muscle synergy is conjectured building blocks that can simplify the construction of motor behaviors." – Emilio Bizzi

- "Central nervous system may use a limited set of control signals to activate a large number of muscles." – Lena Ting

Muscle synergy – Mathematical definition

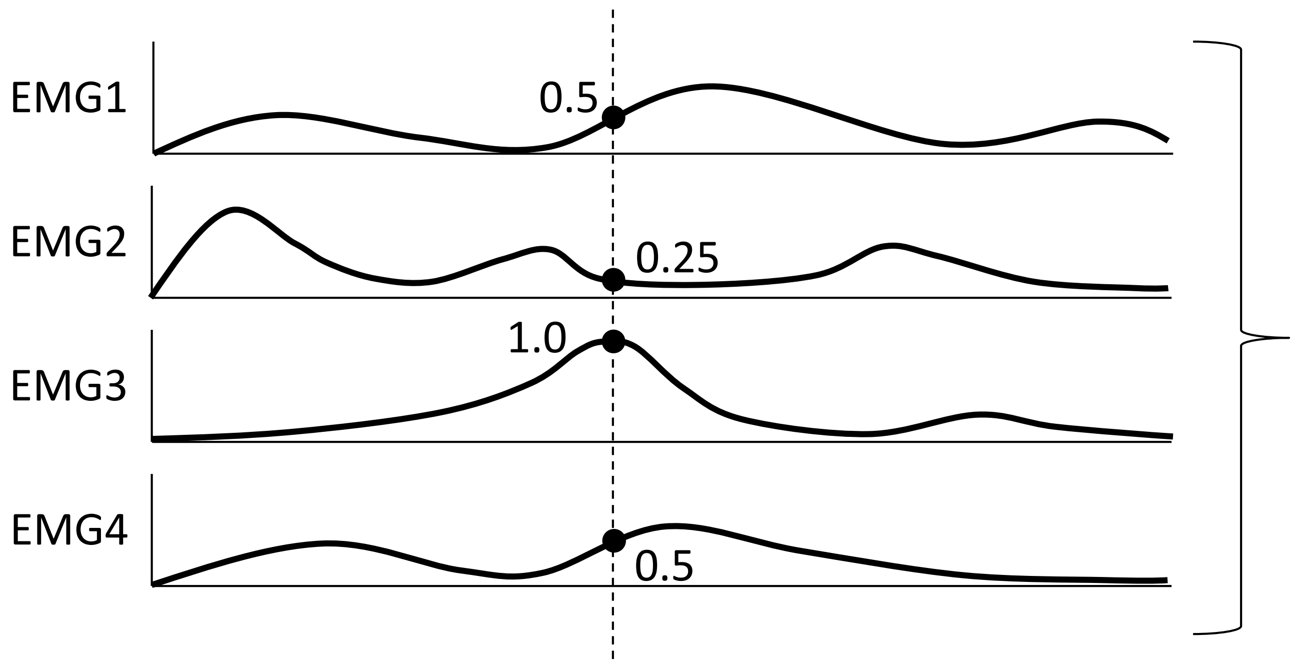
- A muscle activation can be represented as **a linear combination of synergies**.
- Let N_{syn} and i be a number of synergies and an index of synergy, respectively. We define

$$\mathbf{m}_k = \sum_{i=0}^{N_{syn}} \mathrm{c}_{ik}\,\mathbf{w}_i$$

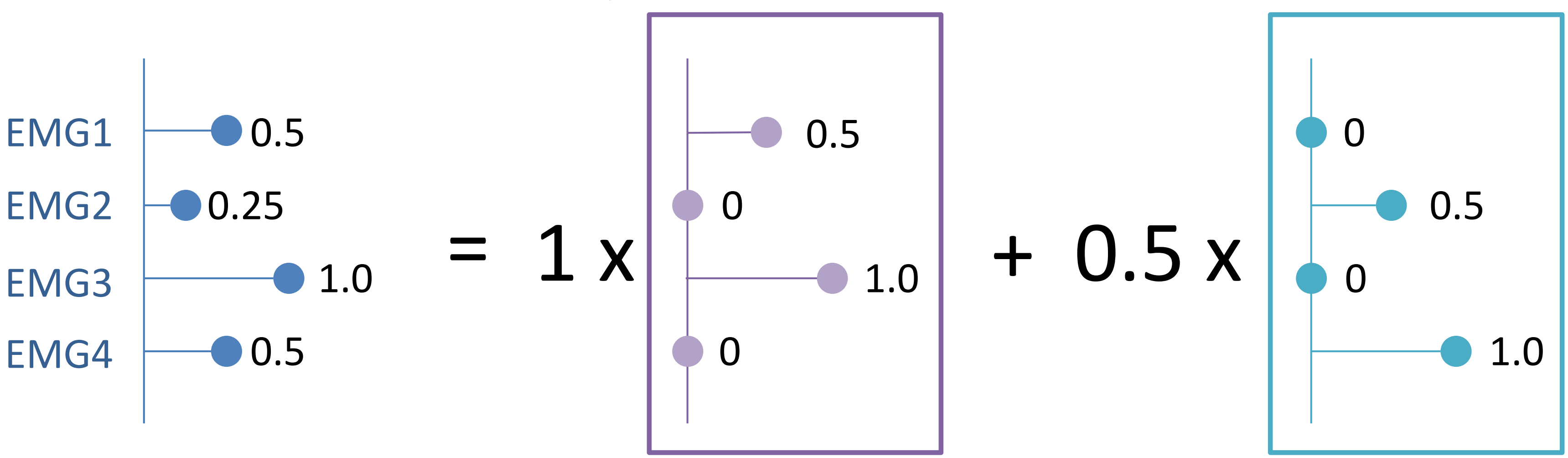
where $\mathbf{m}_k$: a vector representing muscle activation at k
c_{ik} : a coefficient related to $\mathbf{w}_i$ at k
$\mathbf{w}_i$: an i^{th} muscle synergy

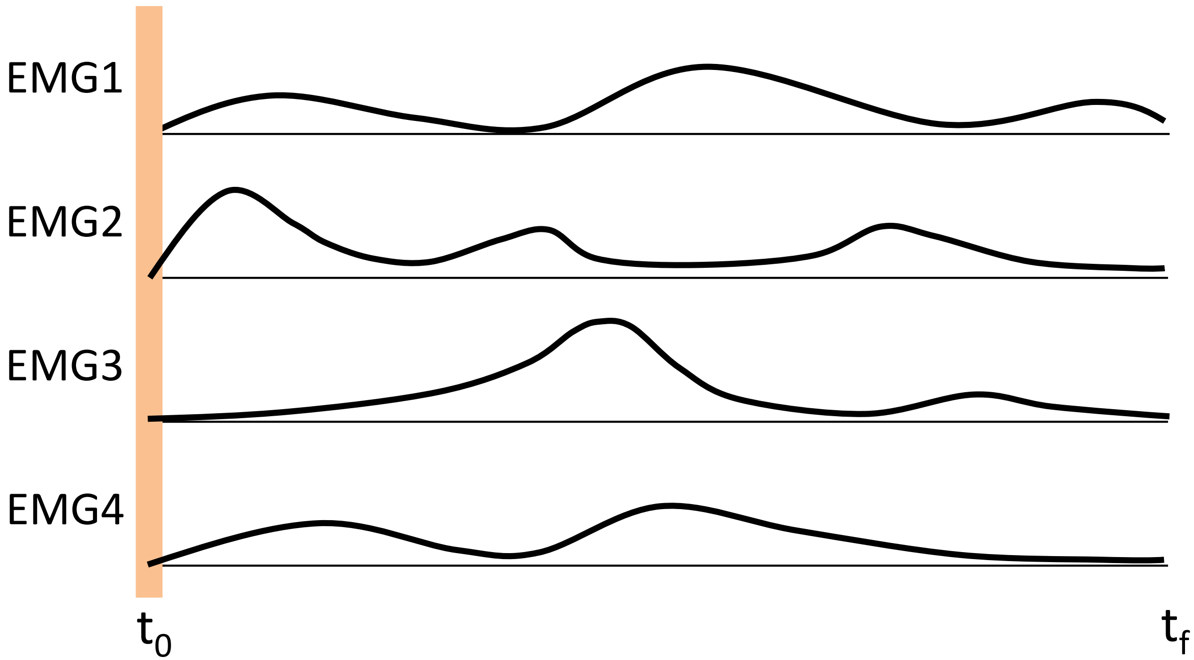
HUman Rehabilitation Group
TEXAS A&M UNIVERSITY

Muscle synergy – graphical example

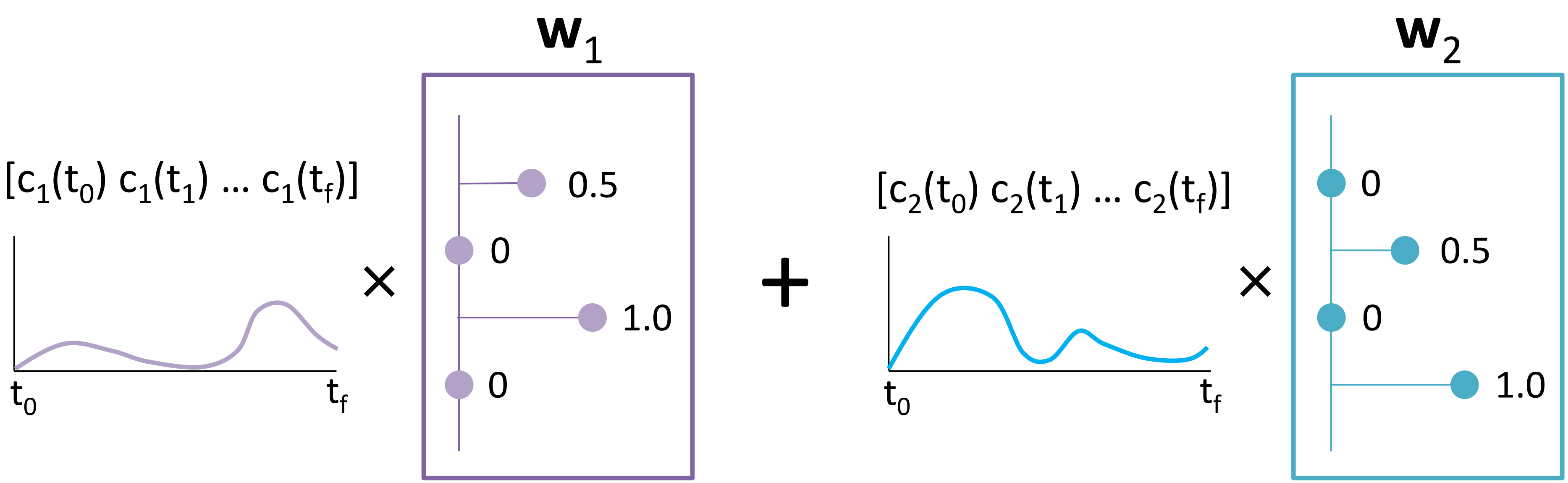


Processed EMG signal vector (rectification, low-pass filter, and integration)





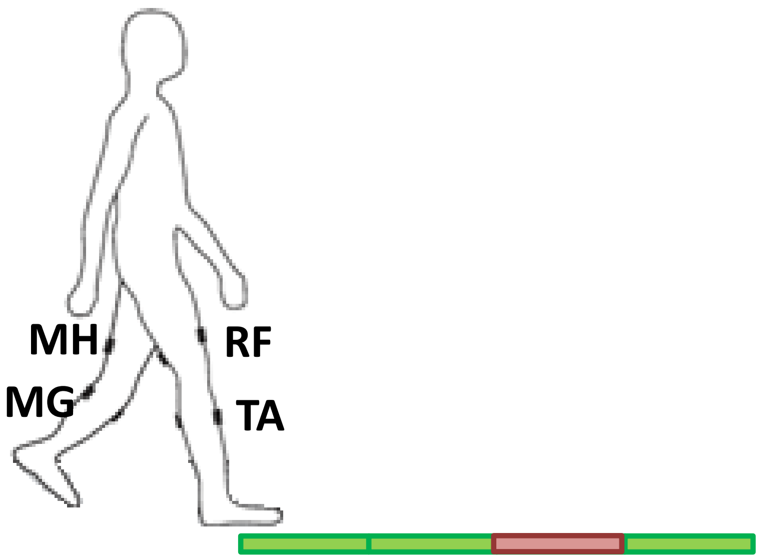
Processed EMG signal vector at the previous slide



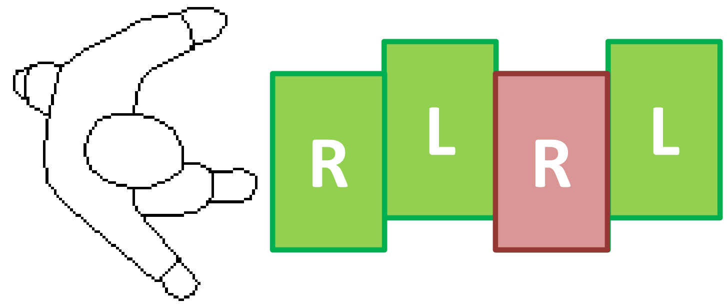
Research questions

- Q1 – What synergies will be the derived for slip and dry-walking?
- Q2 – What will be the difference between severe and mild slip groups in perspective of muscle synergies?
- Q3. – Are there any difference between two groups in perspective of muscle activation pattern and reaction time?

Method – subject and procedure



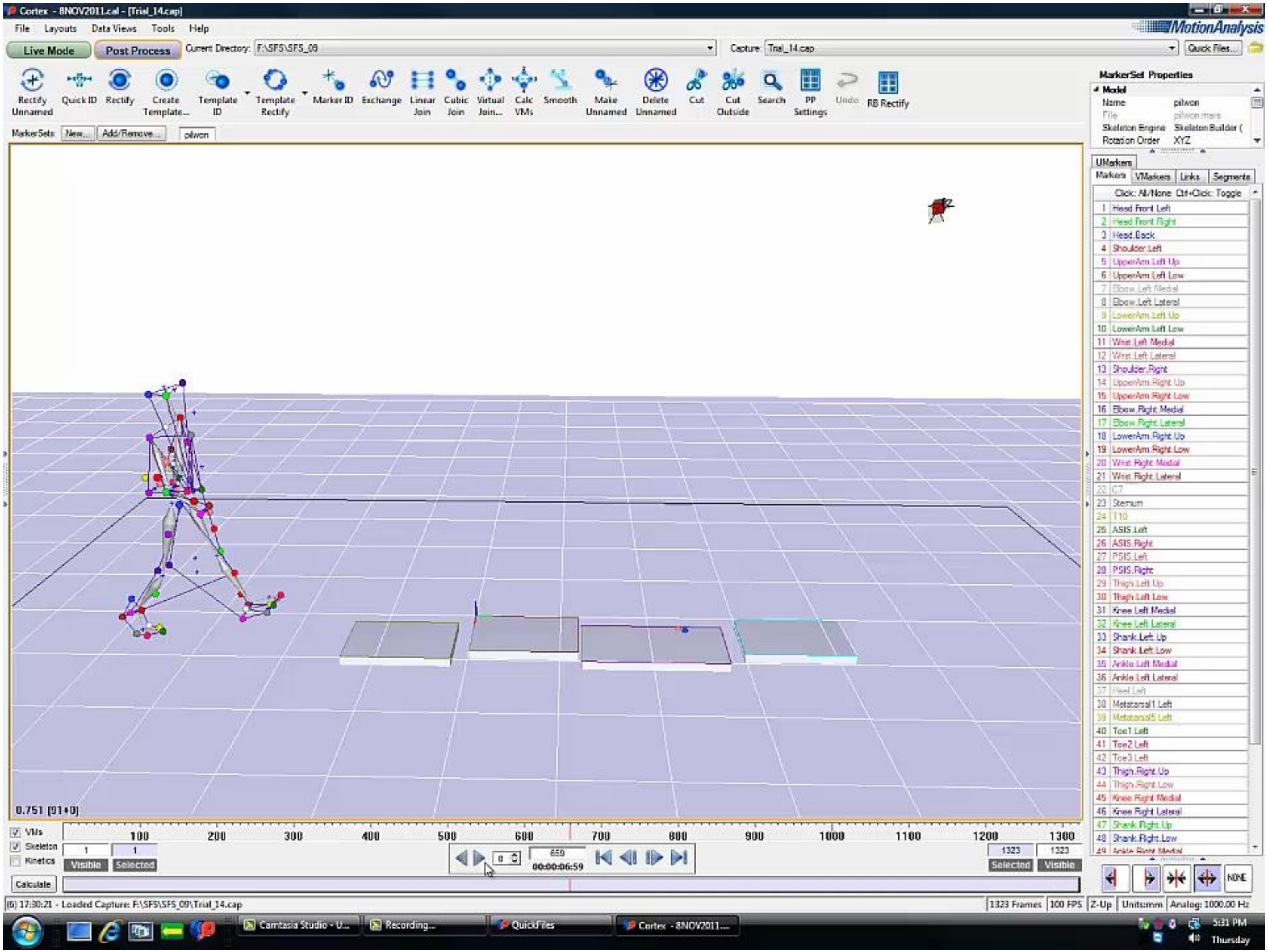
Side view



Top view

- 11 healthy young adults (6 male and 5 female, age=22-33yrs)
- Subjects were instructed to walk on a floor with four plates embedded.
- Four dry-walk trial followed by an unexpected slip trial.
- **The subjects were informed that the surface of all plates would be dry (this induced the unexpected slip)**

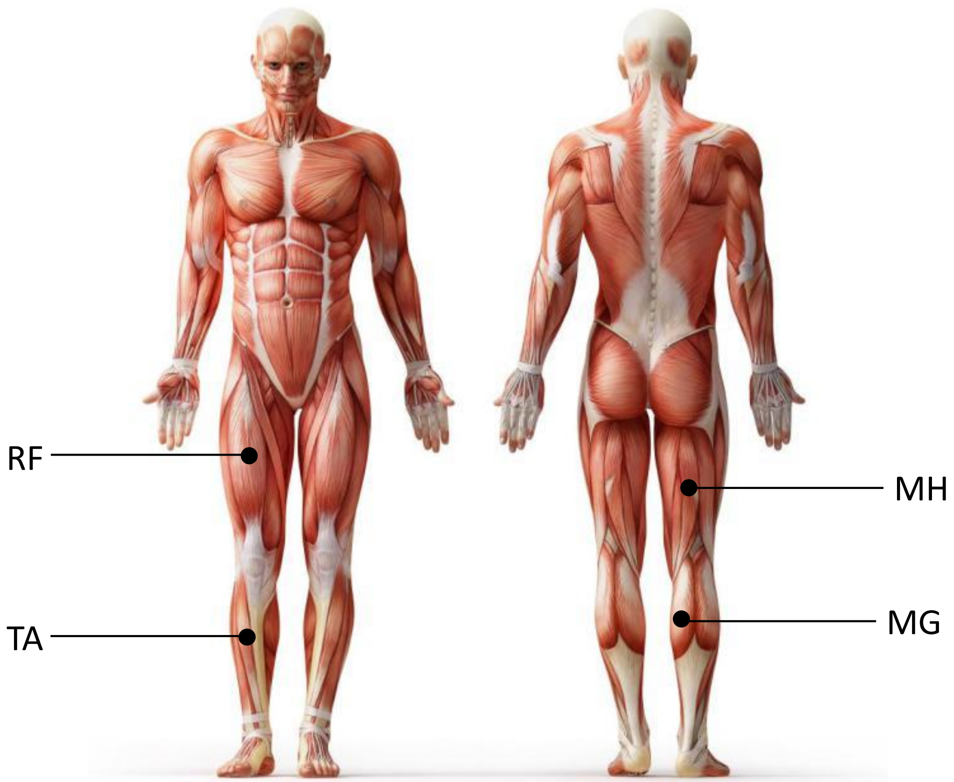
Unexpected slip – demo



Method – Data collection

1. Obtain EMG from 8 leg muscles (4: Right, 4:Left)

EMG#	1	2	3	4	5	6	7	8
Name	RF L	RF R	TA L	TA R	MG L	MG R	MH L	MH R



(http://sowentobarta.wordpress.com)

RF: Rectus Femoris
TA: Tibialis Anterior
MG: Medial Gastrocnemius
MH: Medial Hamstring

Method – Data collection (cont'd)

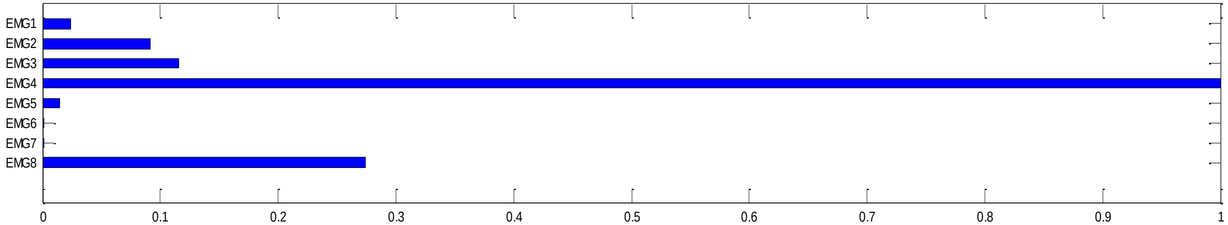
2. For dry-walking and slip experiment, record heel contact time for each plate.
3. We observe 300ms interval after 3rd plate heel contact time for both slip and dry-walk analysis

Method – analysis

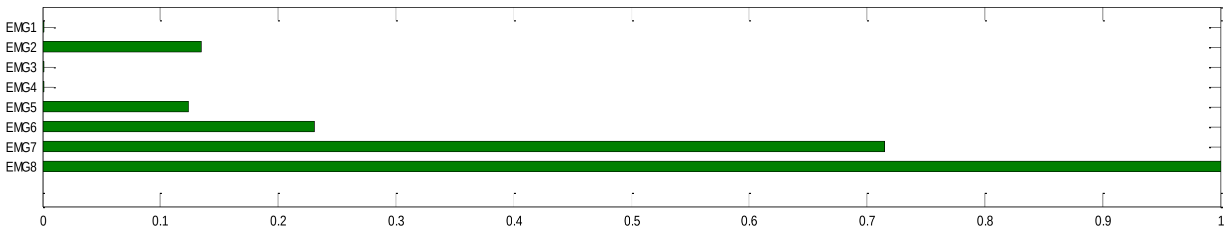
1. Group the subject into "severe slip" and "mild slip" groups (severe slip has heel speed larger than 0.7m/s during slip).
2. Find muscle synergy for dry-walking and slip data.
3. Analyze muscle synergies and weights(coefficients) for dry-walking and slip trials.
4. Perform Mann-Whitney U test to compare the weights of the two groups for dry-walking and slip trials.

Results – synergies from slip data

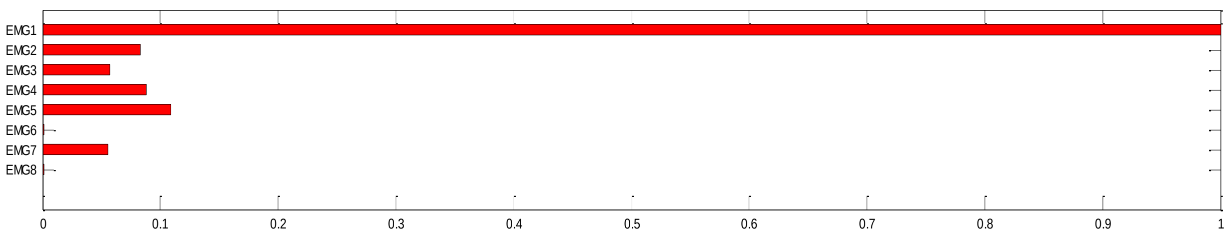
- 4 Synergies to control a posture during the slip



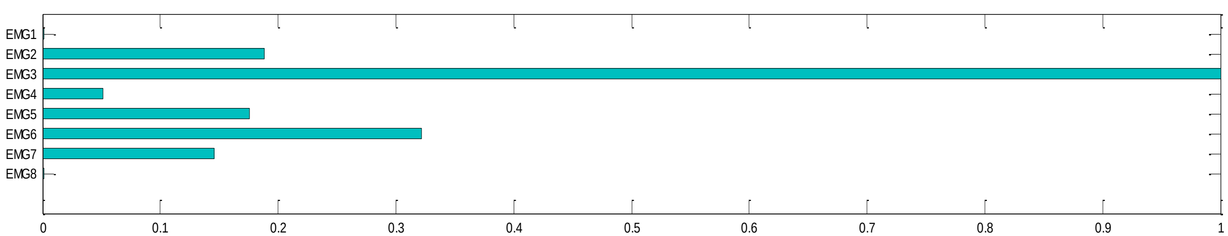
TA Right



MH Right



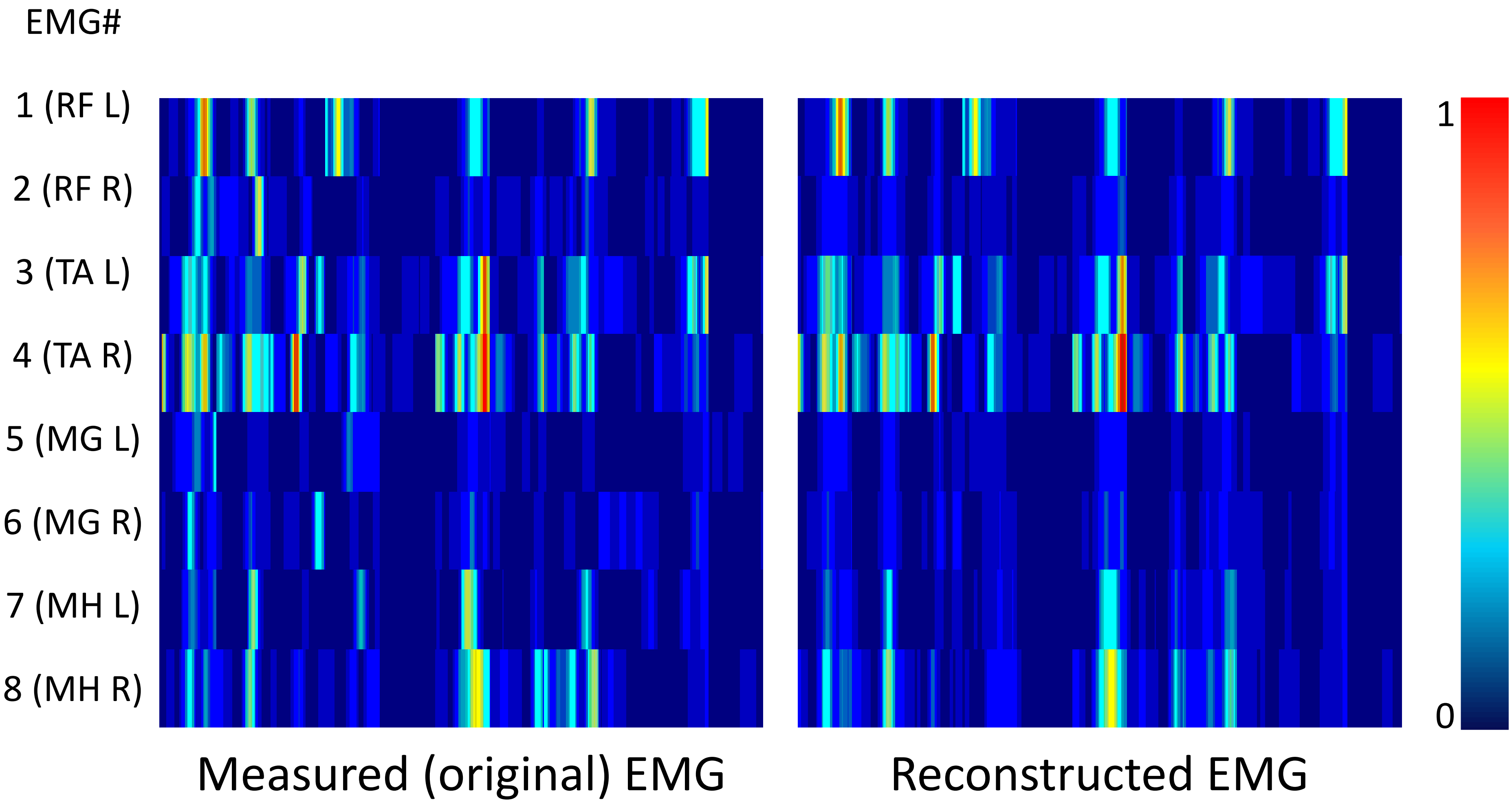
RF Left



TA Left

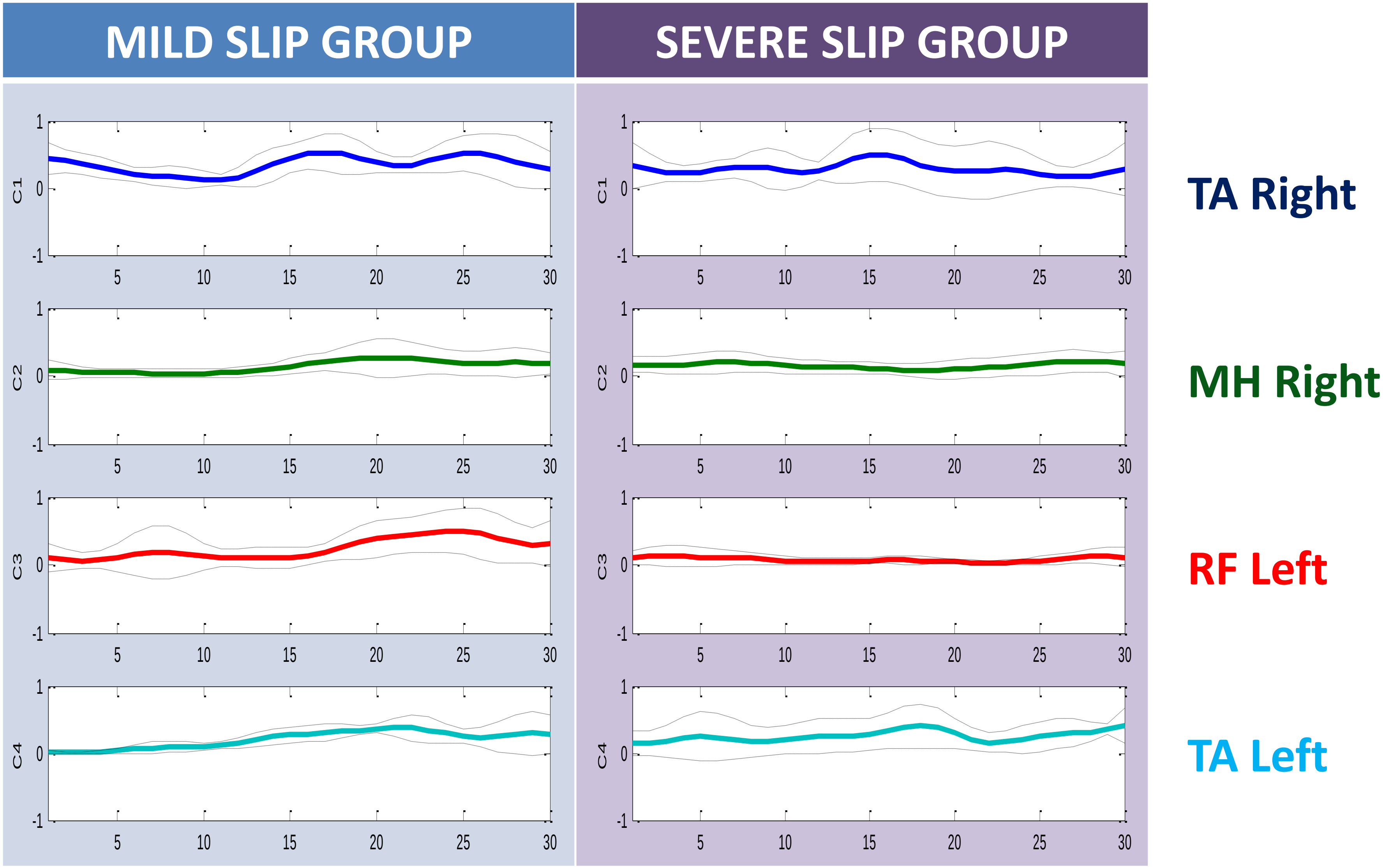
Results – EMG reconstruction

- Measured EMG vs Reconstructed EMG

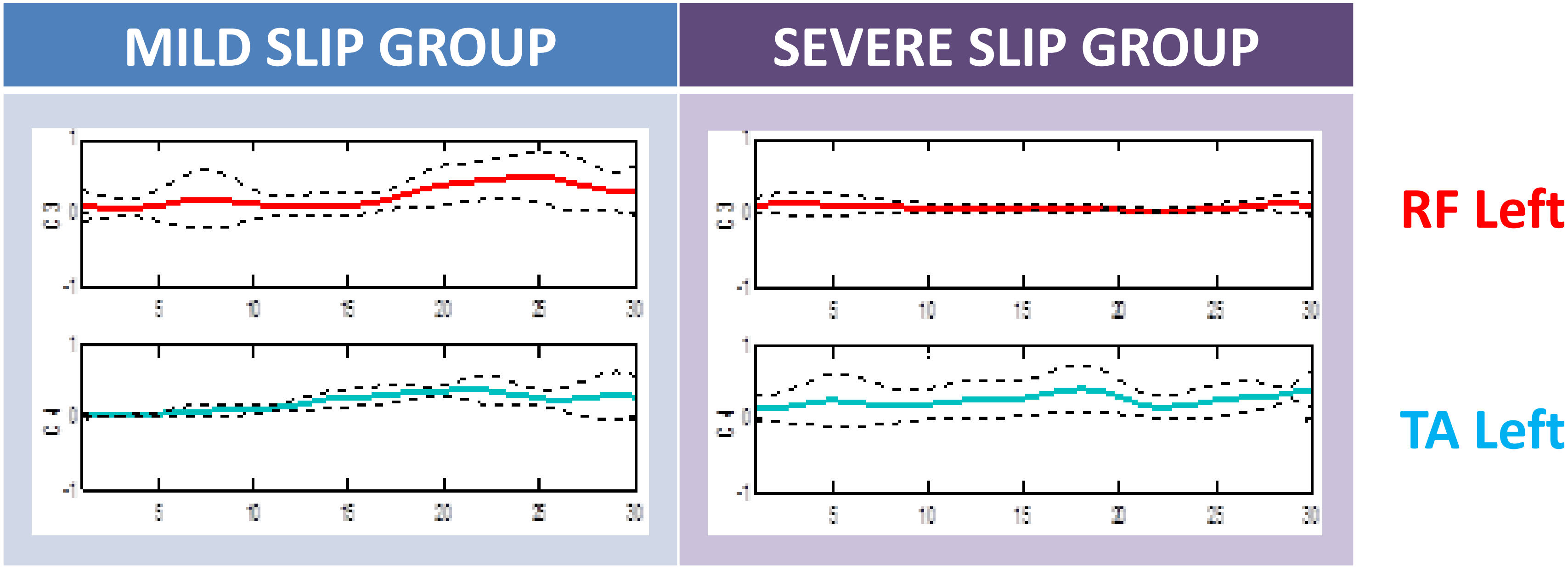


Results – ensemble mean of weights along time step

- Ensemble mean of weights of two group.



For further analysis, we observe RF L and TA L

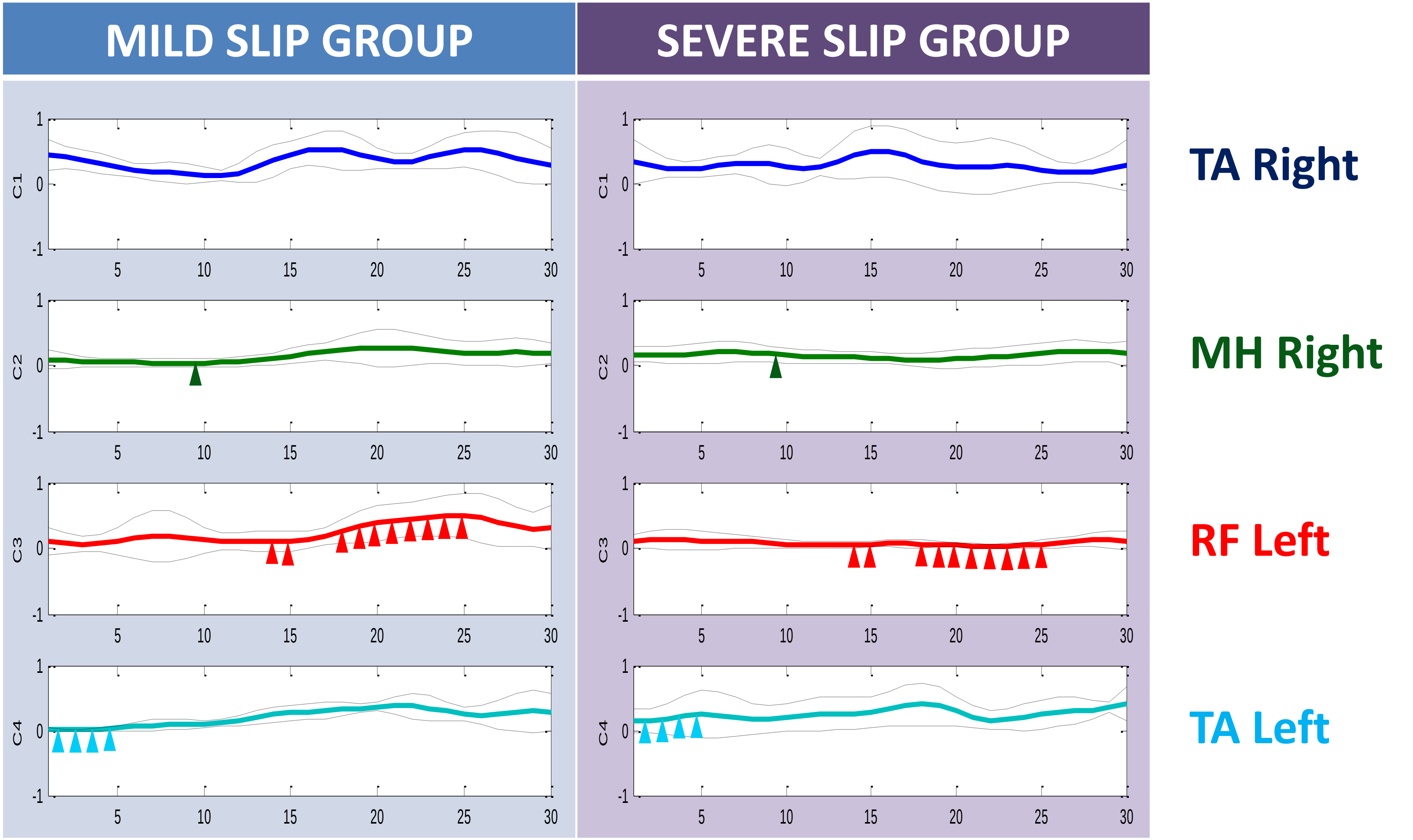


This result can be interpreted as

- Mild group subjects could cope with slip by quickly reacting to slip, moving the center of pressure (CoP) closer to supporting leg (left), and controlling a posture by RF L.
- TA L was activated followed by RF L to control a left ankle movement.
- Severe group did not have enough RF L support, and keep using TA L to balance a posture.

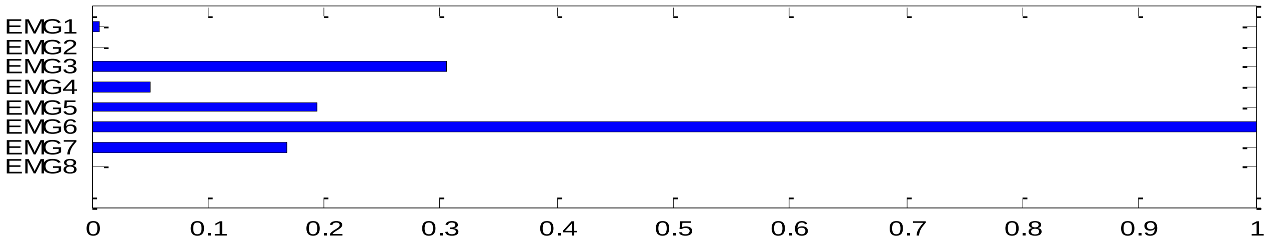
Statistical analysis – Mann-Whitney U test

- We mark the time step for $p < 0.05$ which means there exists significant difference between two groups' weight for RF L and TA L.

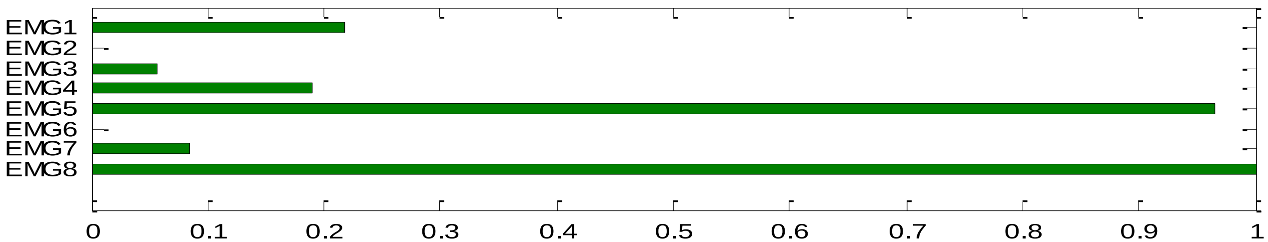


Results – synergies from dry-walking data

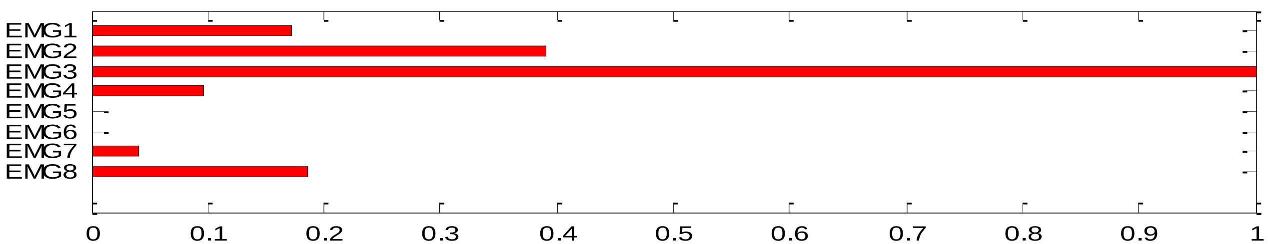
- 4 Synergies to control a posture during the dry-walking



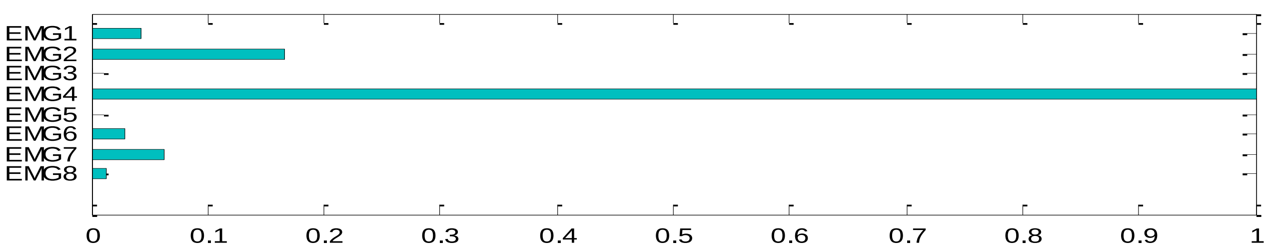
MG Right



MH Right (MG L)



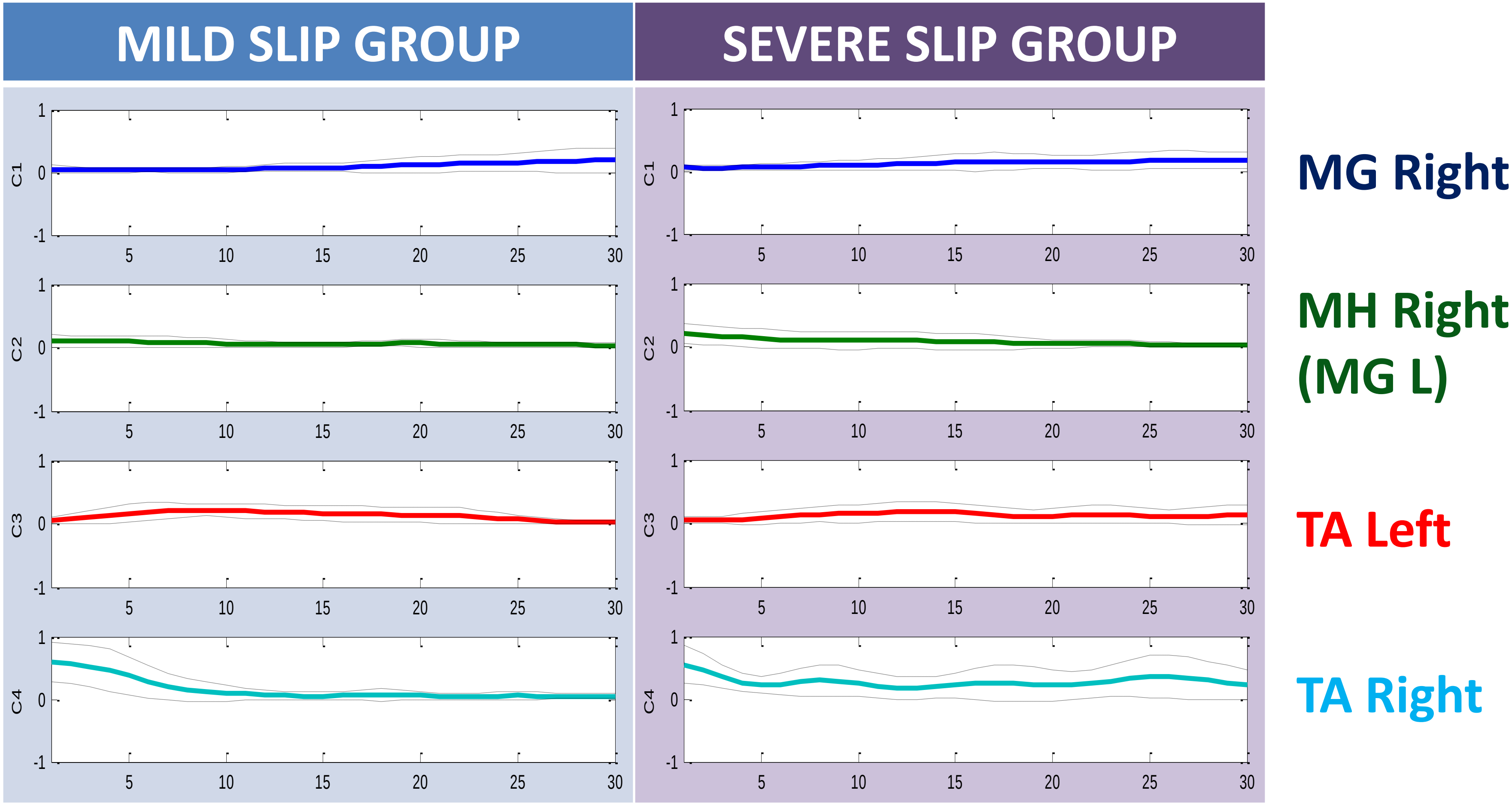
TA Left



TA Right

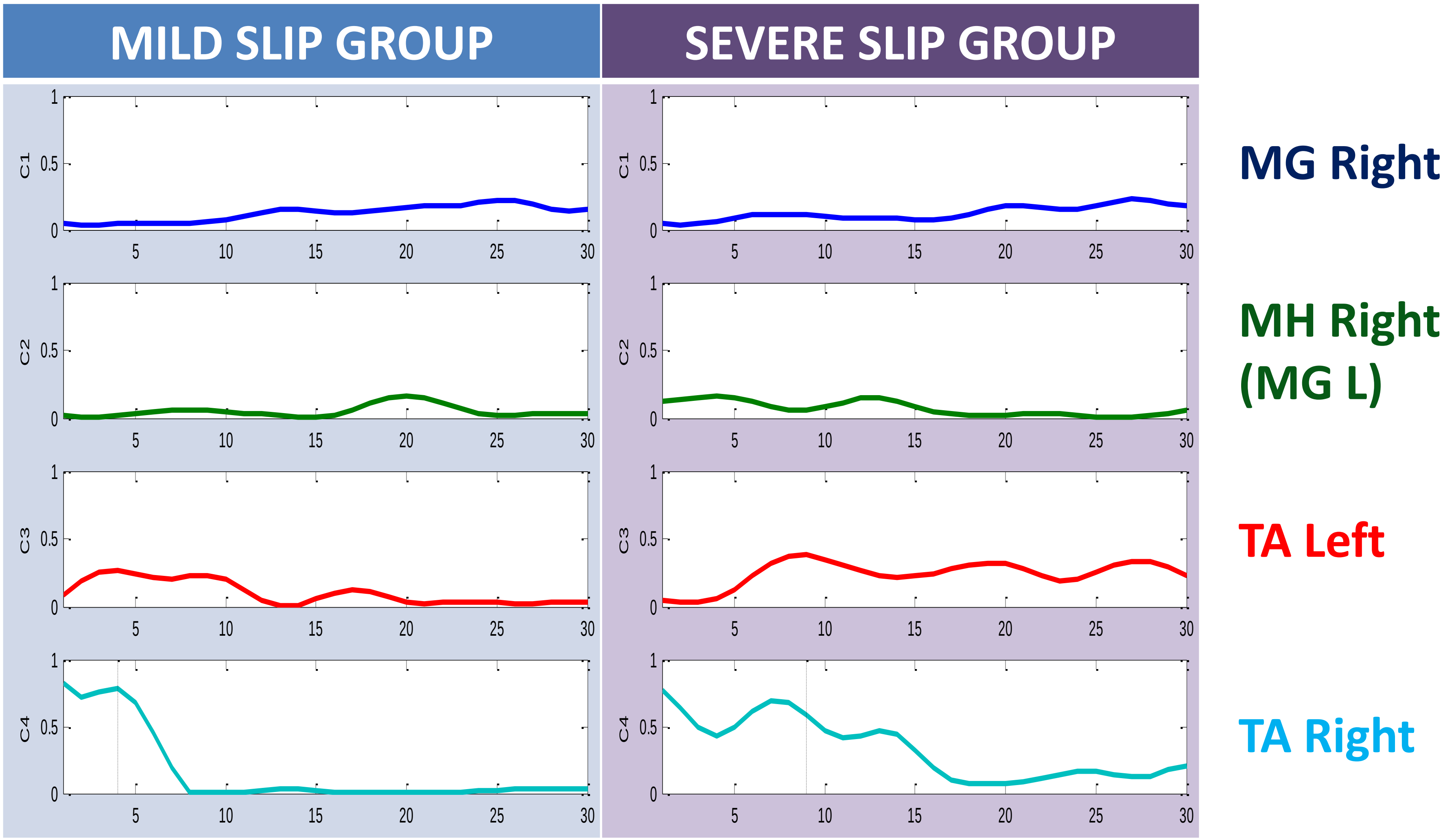
Results – weight of synergies along time step

- From Mann-Whitney U test, we observed that there existed marginally difference between two groups' weights, but no significant difference was found.



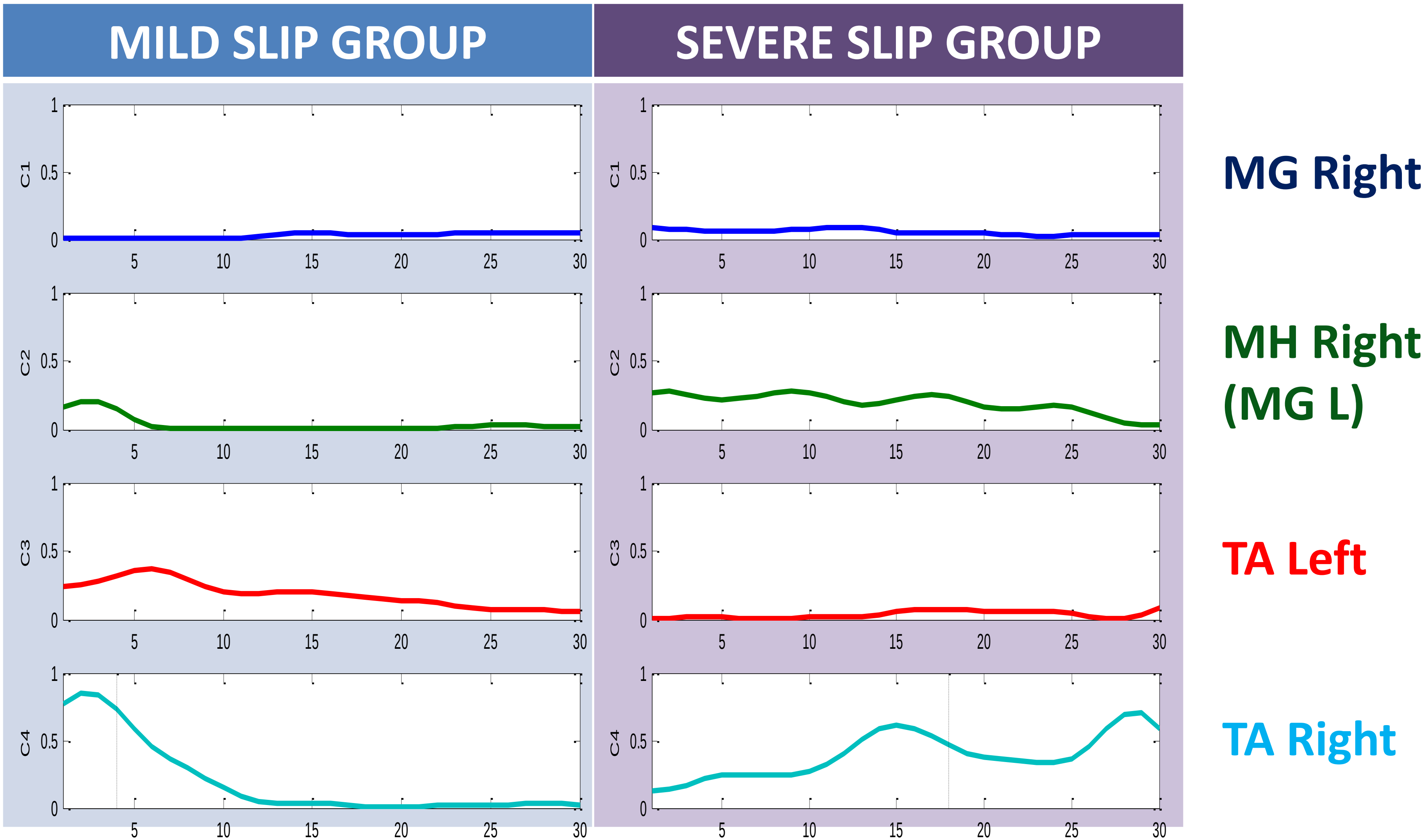
Results – Reaction time (the 1st subject in each group)

- We observe a time step that TA R integration along k goes over 50% of total integration.



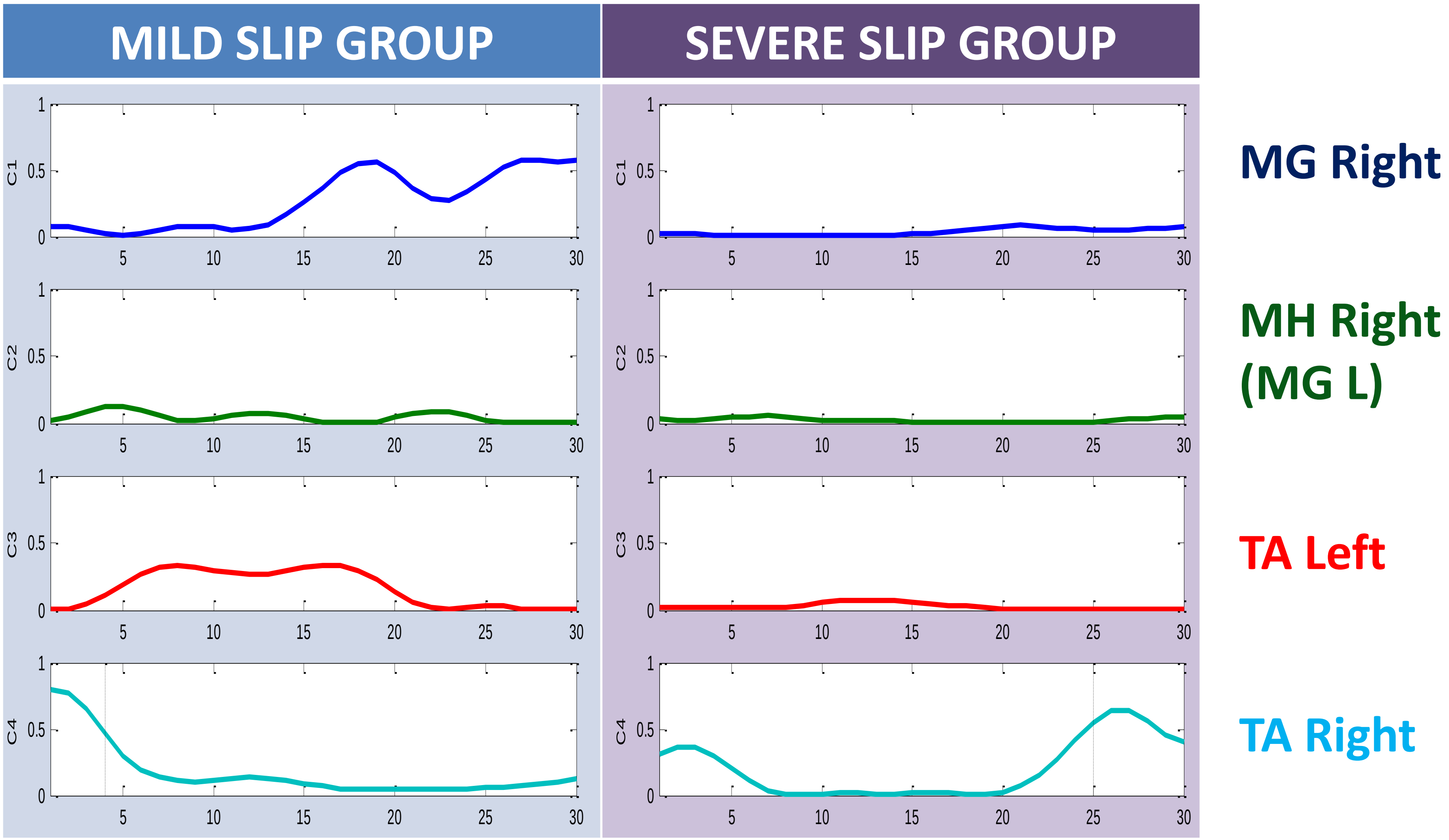
Results – Reaction time (the 2nd subject in each group)

- We observe time step when TA R integration along k goes over 50% of total integration.

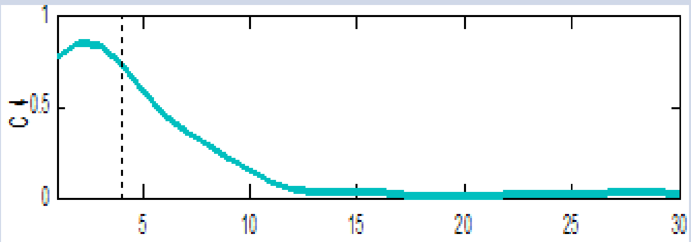
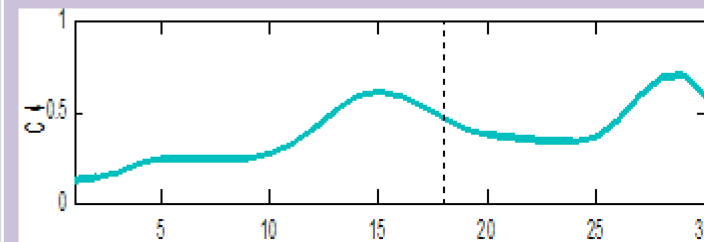


Results – Reaction time (the 3rd subject in each group)

- We observe time step when TA R integration along k goes over 50% of total integration.



- From this further analysis, we found that a time step that the integration of TA R goes over 50% of total integration tends to be delayed for the severe slip group.

MILD SLIP GROUP	SEVERE SLIP GROUP
	

TA Right

This result can be interpreted as

- Managing the severity of slip is related to a function of TA R after heel contact.
- Generally, it is known that TA performs deceleration of ankle joint plantarflexion and resist foot pronation (Murley, Menz, and Landorf, 2009)(Hunt, Smith, and Torode, 2001)

Gait Cycle - TA pattern

- This result is consistent to the outcomes of gait cycle pattern

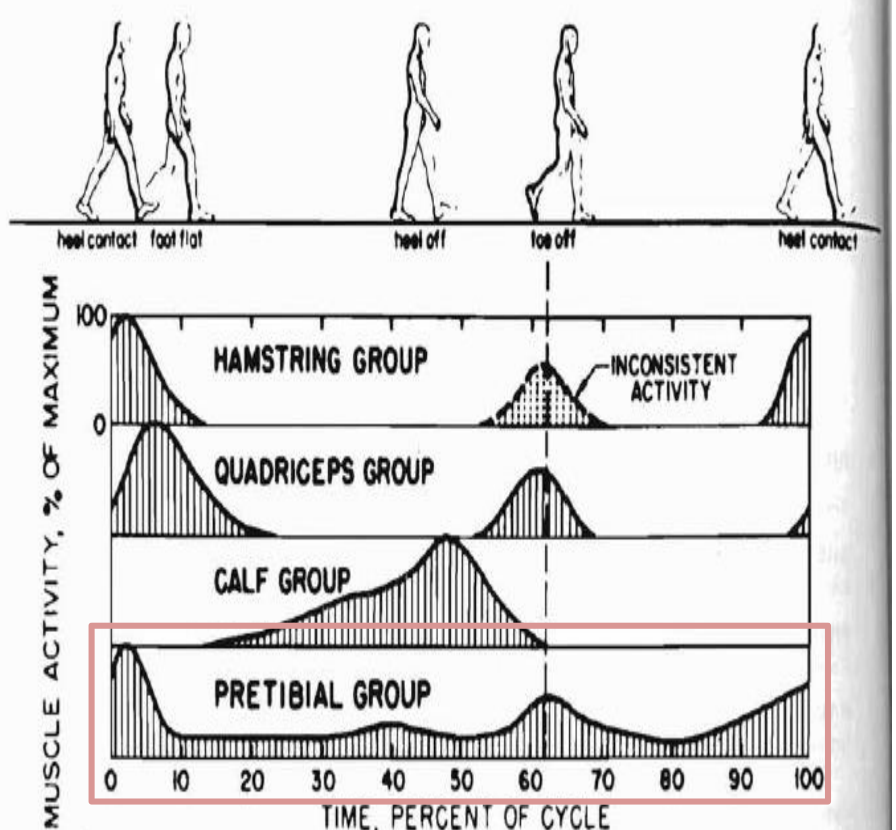


FIGURE 1.
Electromyographic Gait Patterns. The average EMG patterns of several muscle groups is plotted as a function of normalized time. This data is from Eberhart (1).

[Shiavi et al, 1981] Variability of electromyographic patterns for level-surface walking through a range of self-selected speeds. Prosthetics research, vol 18. No. 1, pp 5-14.

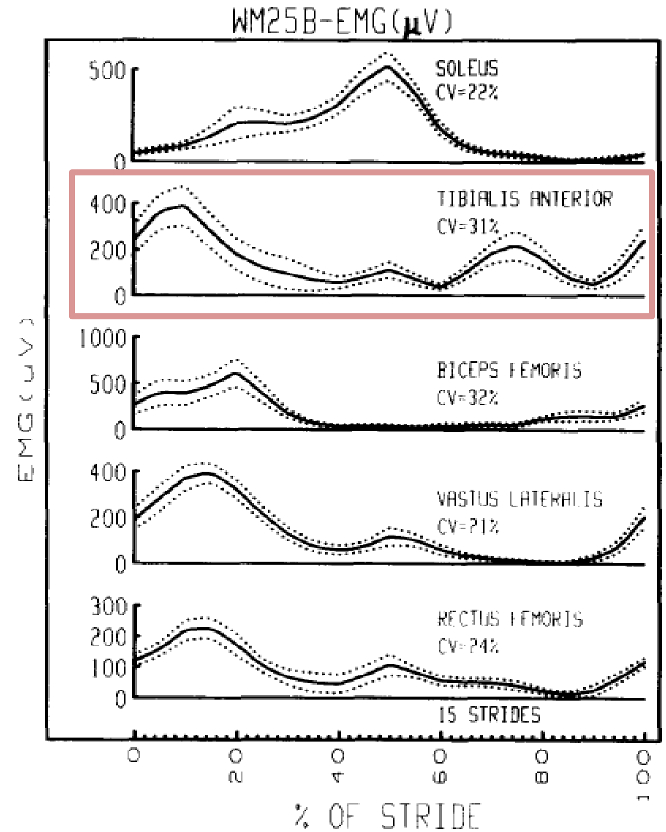


Fig. 2. Ensemble average of EMG profiles from 15 strides for a typical normal subject. Solid line is the average EMG at each 5% of the stride period, the dotted line indicates ±1 S.D. The CV is indicated for each muscle. The mean cadence for the 15 strides was 114±2.

[Winter and Yack, 1987] EMG profiles during normal human walking: stride-to-stride and inter-subject variability, Electroencephalography and clinical neurophysiology, 67: 402-411.

Conclusion

- In this research, we found the slip-related and dry-walking-related muscle synergy and compared “severe” and “mild” slip groups in synergy perspective.

- For each trial, 4 dominant muscles in the synergies were
  Dry-walk: MG R, MH R, TA L, and TA R
  Slip: TA R, MH R, RF L, and TA L

- For slip trial, Mann-Whitney U test showed that there exists some time interval wherein the weight of RF L and TA L between the two groups are significantly different.

- For dry-walking trial, a time step that the integration of TA R goes over 50% of total integration tends to be delayed in severe slip group.

Take home message

The role of TA is important for both walk and slip.