# Slip-Related Muscle Synergy during Human Walking

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# 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

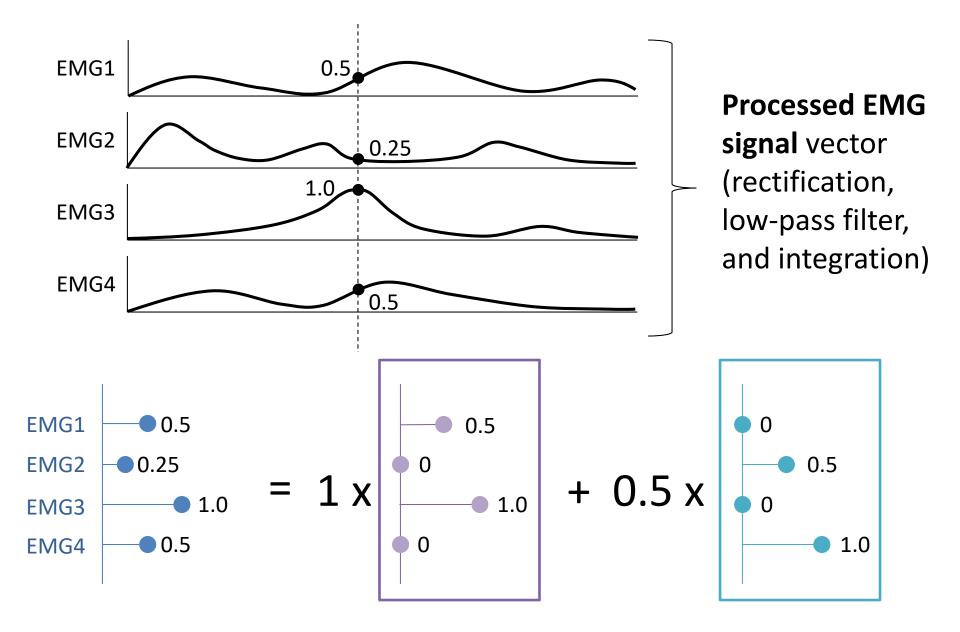
- A muscle activation can be represented as a linear combination of synergies.
- Let N<sub>syn</sub> and *i* be a number of synergies and an index of synergy, respectively. We define

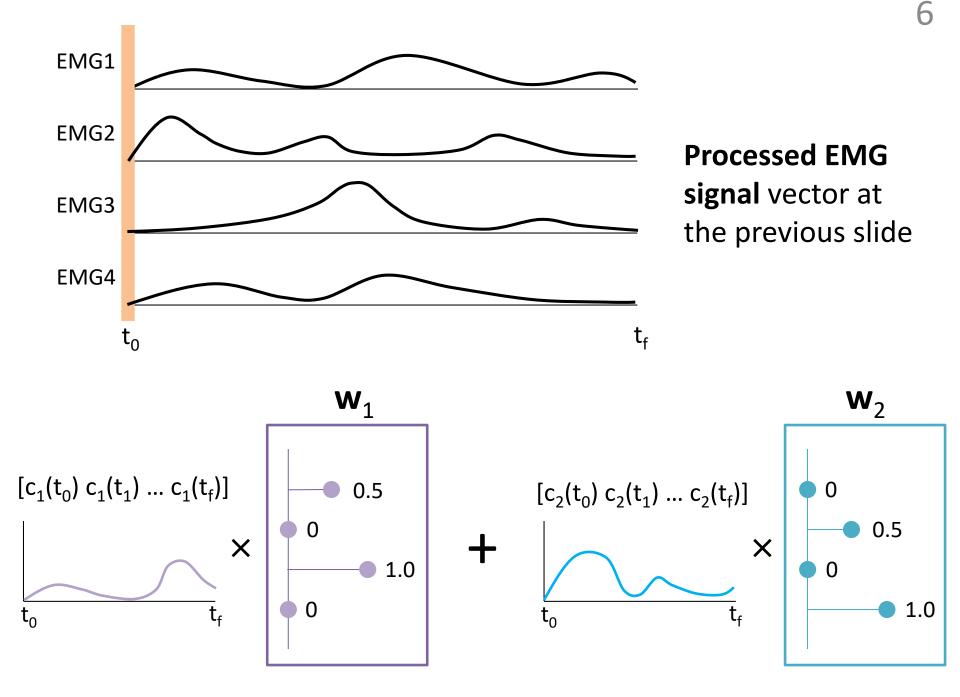
$$\mathbf{m}_{k} = \sum_{i=0}^{N_{syn}} \mathbf{c}_{ik} \mathbf{w}_{i}$$

where m<sub>k</sub> : a vector representing muscle activation at k
c<sub>ik</sub> : a coefficient related to w<sub>i</sub> at k
w<sub>i</sub> : an i<sup>th</sup> muscle synergy



## Muscle synergy – graphical example



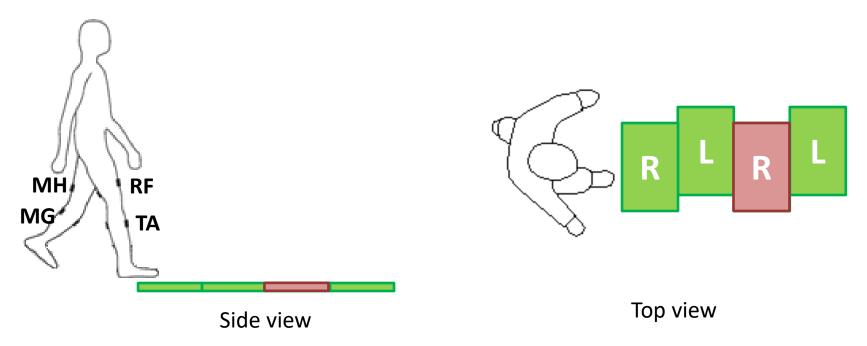


# **Research questions**

- Q1 What synergies will be the derived for slip and drywalking?
- 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



- 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)

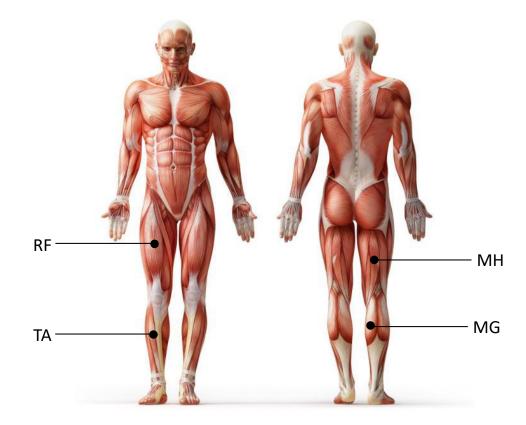
## Unexpected slip – demo

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# 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	MHL	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 3<sup>rd</sup> plate heel contact time for both slip and dry-walk analysis

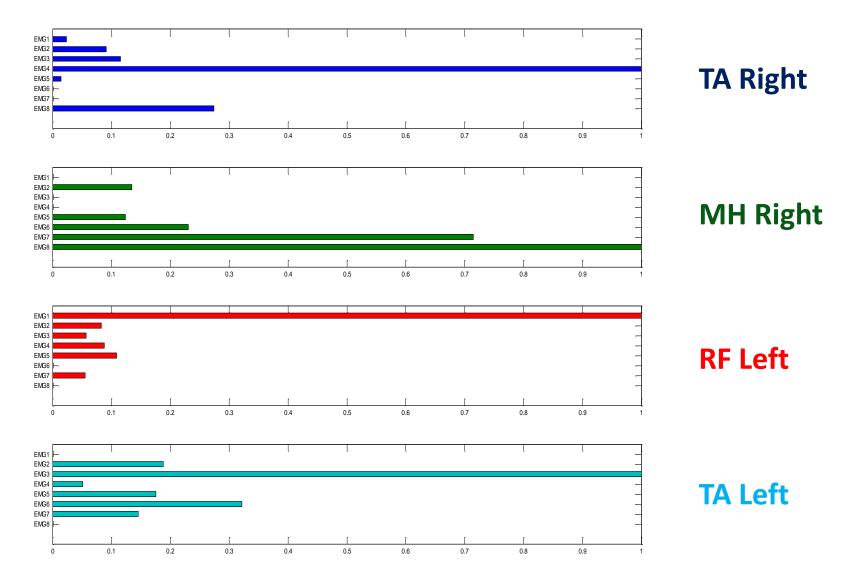
# Method – analysis

- 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 drywalking and slip trials.
- 4. Perform Mann-Whitney U test to compare the weights of the two groups for dry-walking and slip trials.



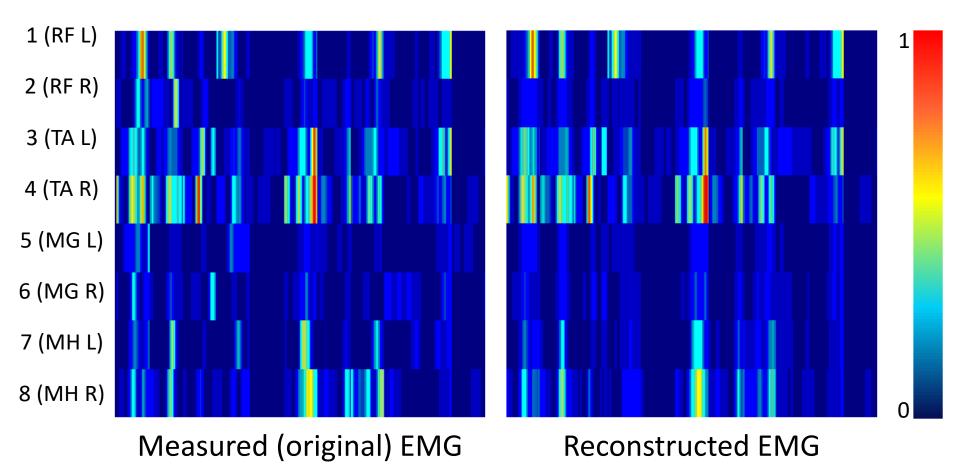
## **Results** – synergies from slip data

• 4 Synergies to control a posture during the slip



### **Results** – EMG reconstruction

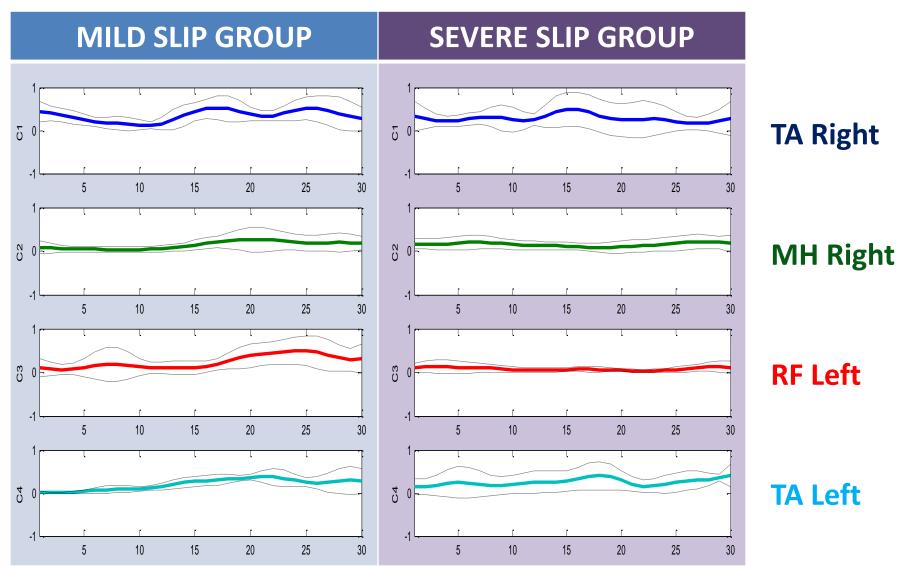
• Measured EMG vs Reconstructed EMG EMG#



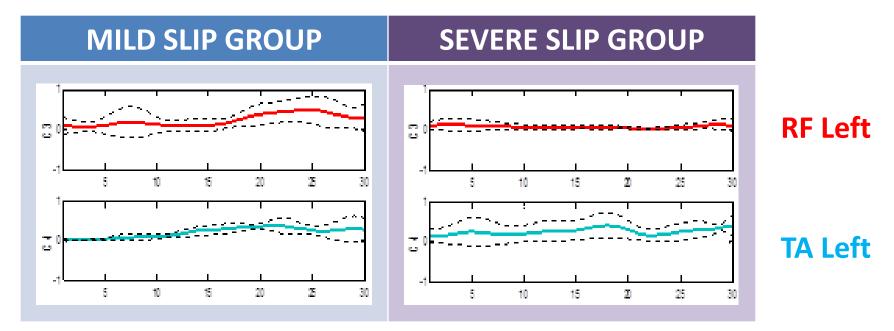
#### Results – ensemble mean of weights along time step

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• Ensemble mean of weights of two group.



## For further analysis, we observe RF L and TA L 15



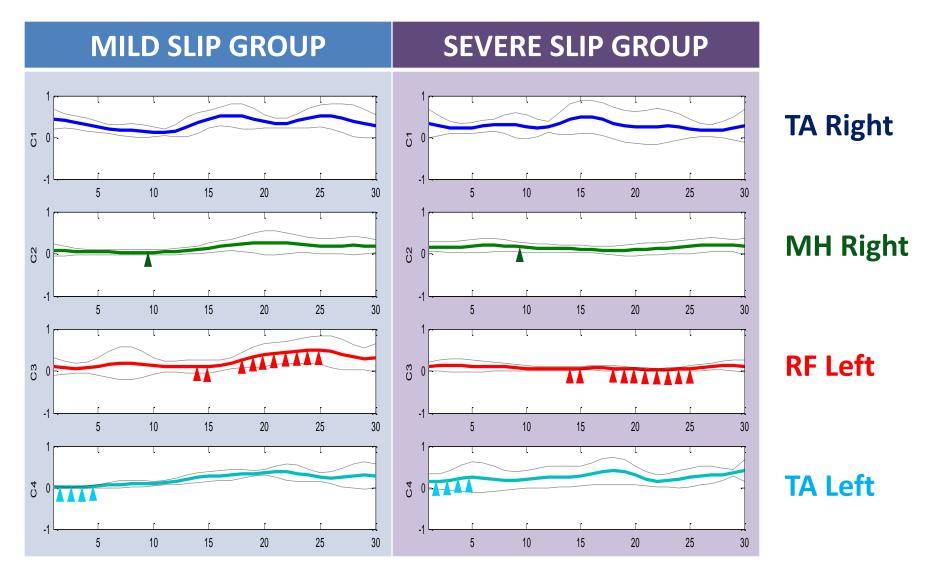
#### This result can be interpreted as

- 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

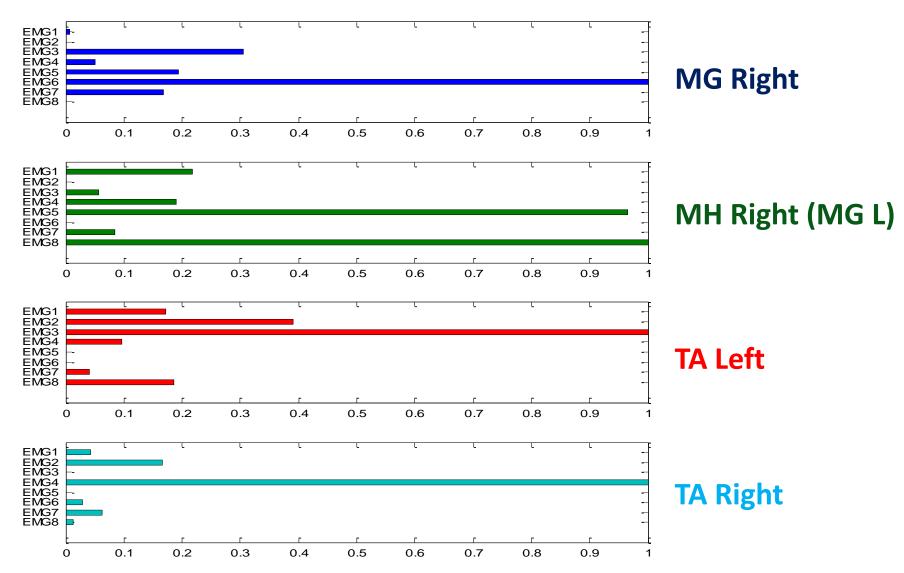
 We mark the time step for p < 0.05 which means there exists significant difference between two groups' weight for RF L and TA L.

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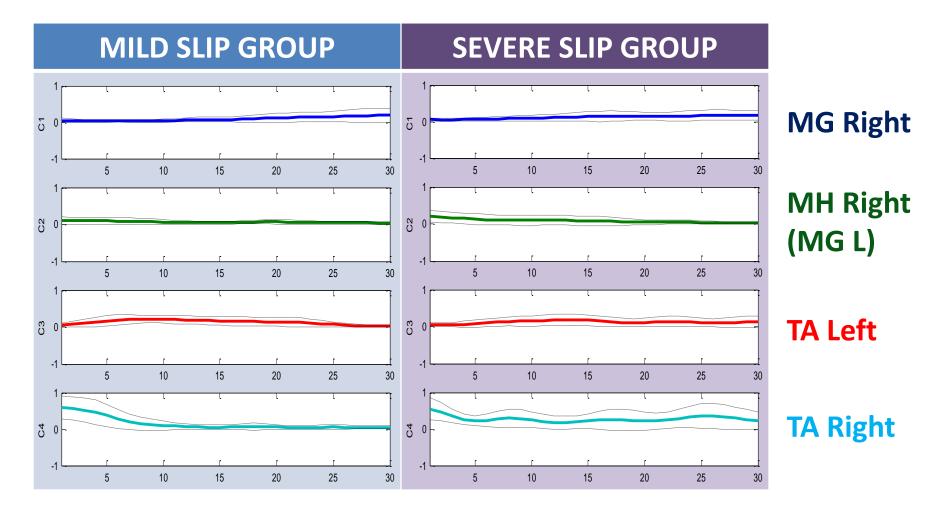
## Results – synergies from dry-walking data

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



### Results – weight of synergies along time step

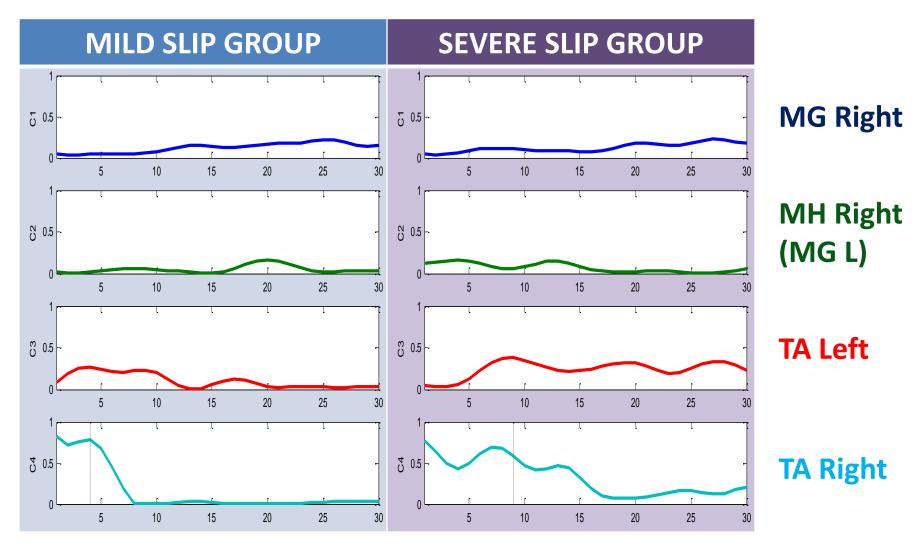
 From Mann-Whitney U test, we observed that there existed marginally difference between two groups' weights, but no significant difference was found.



#### Results – Reaction time (the 1<sup>st</sup> subject in each group)

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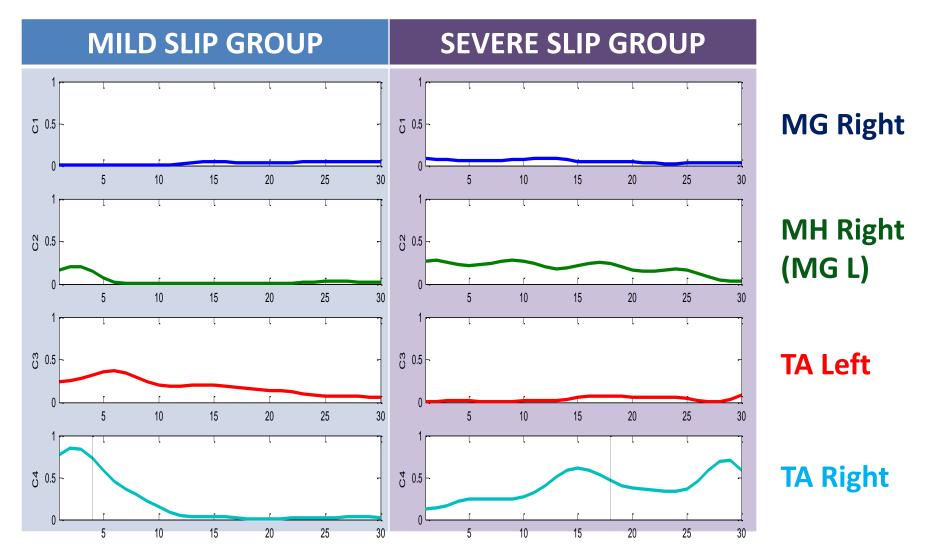
• We observe a time step that TA R integration along k goes over 50% of total integration.



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

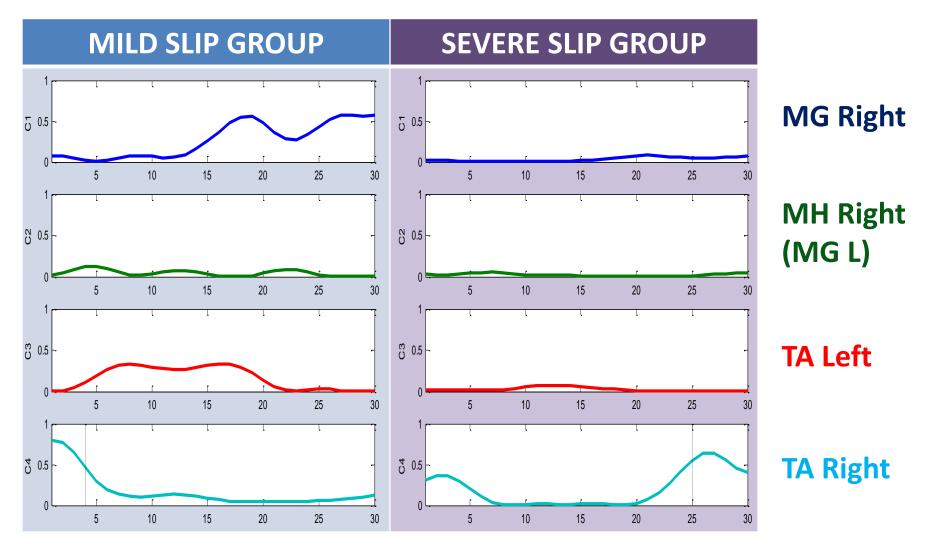
• We observe time step when TA R integration along k goes over 50% of total integration.

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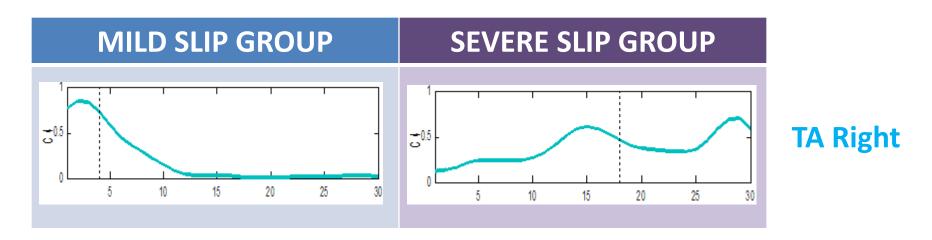


**Results** – Reaction time (the 3rd subject in each group)

• 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.

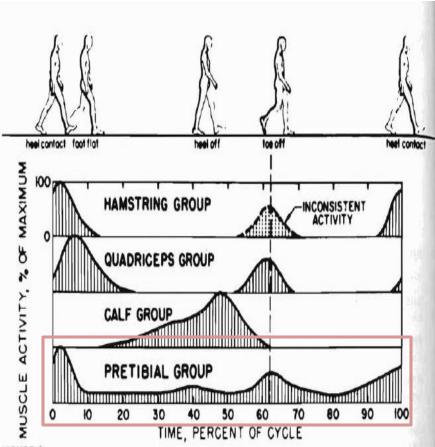


#### This result can be interpreted as

- 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.

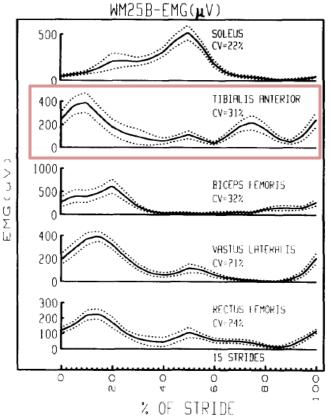


Fig. 2. Ensemble average of EMG profiles from 15 strides for a typical normal subject. Solid line is the average EMG at each 5% of the stride period, the dotted line indicates  $\pm 1$  S.D. The CV is indicated for each muscle. The mean cadence for the 15 strides was  $114 \pm 2$ .

[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.

