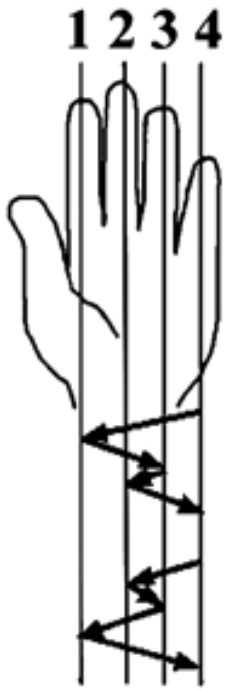
The effect of behavioral interference on the kinematics of a movement sequence during learning

Jason Friedman

Dept. Physical Therapy
Tel Aviv University
Joint work with Maria Korman (Haifa University)

1st November, 2015

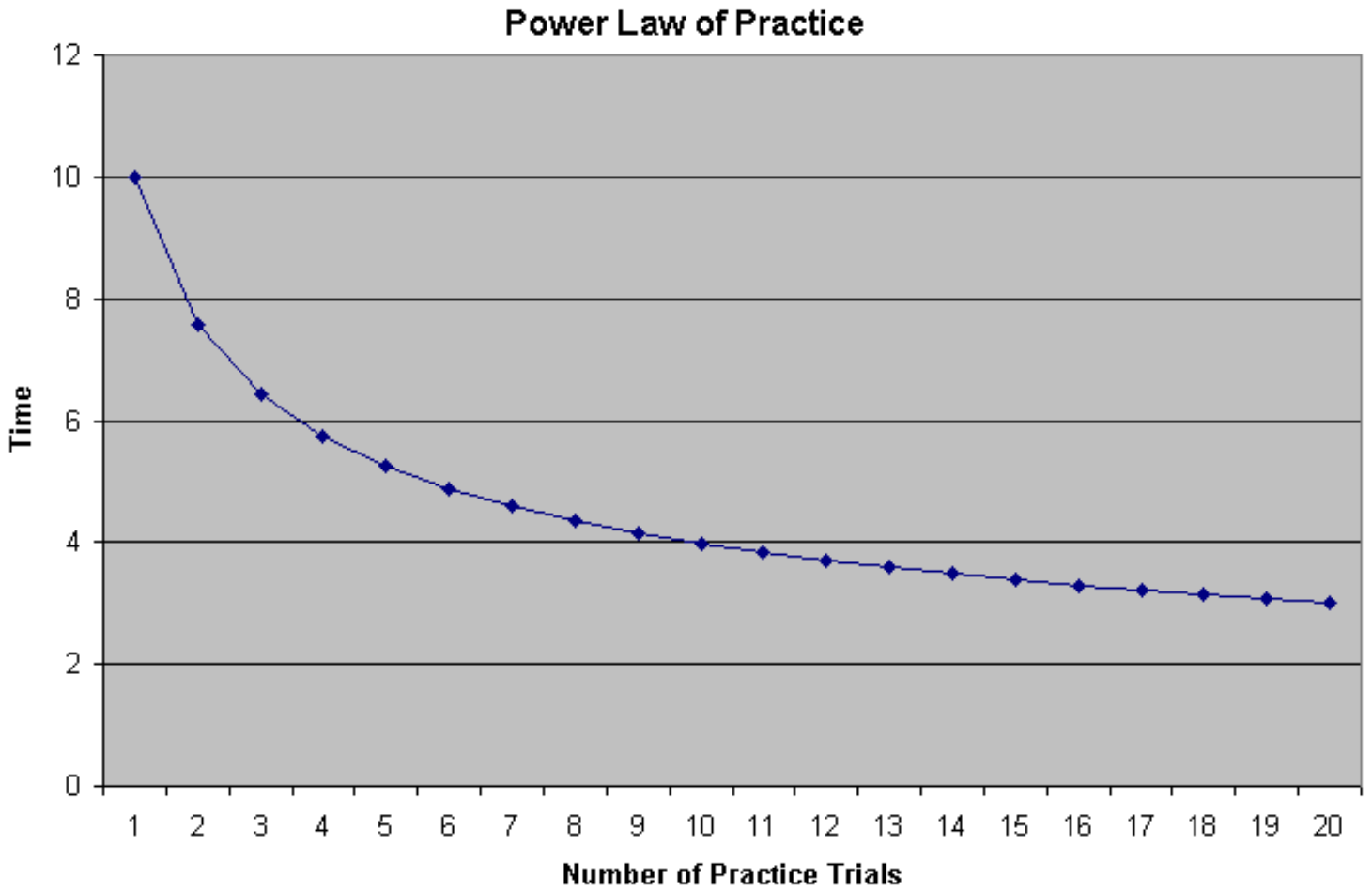
BACKGROUND - MOTOR SEQUENCE LEARNING



Sequence A: 4, 1, 3, 2, 4

Sequence B: 4, 2, 3, 1, 4

BACKGROUND - POWER LAW

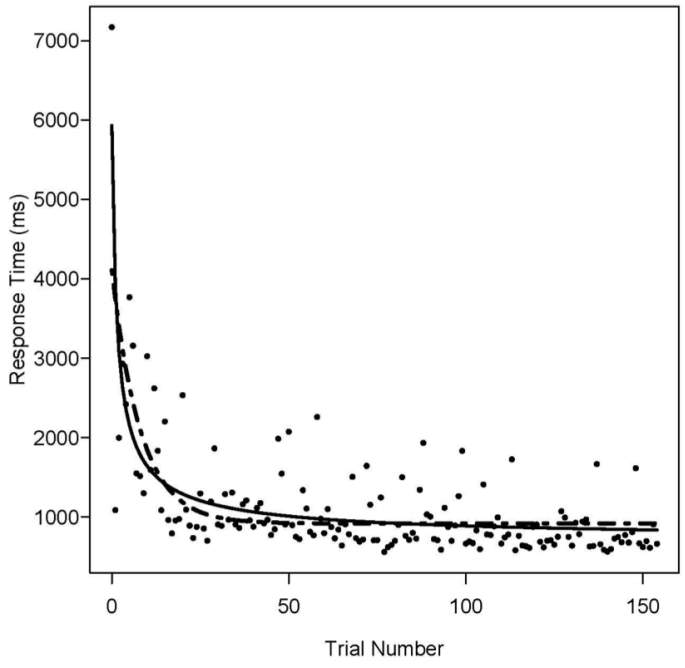


Power law: $T = N^{-\beta}$

N = number of practice trials

β = learning rate

BACKGROUND - POWER LAW



- Power law: $T = N^{-\beta}$
- Exponential : $T = e^{-\alpha N}$
- N = number trials, α or β are the learning rate
- Power law implies reduction in learning rate with practice
- Exponential implies constant *relative* rate of learning (Heathcote et al., 2000)

SLOW AND FAST LEARNING

- Studies have highlighted the importance of time and not only the number of trials in learning (e.g. Karni et al., 1998)
- There are two broad types of learning observed:
  - Fast, within-session learning
  - Slow, between-session learning
- Both are experience-dependent

FAST LEARNING

- Fast learning occurs within a training session
- There is a habituation effect

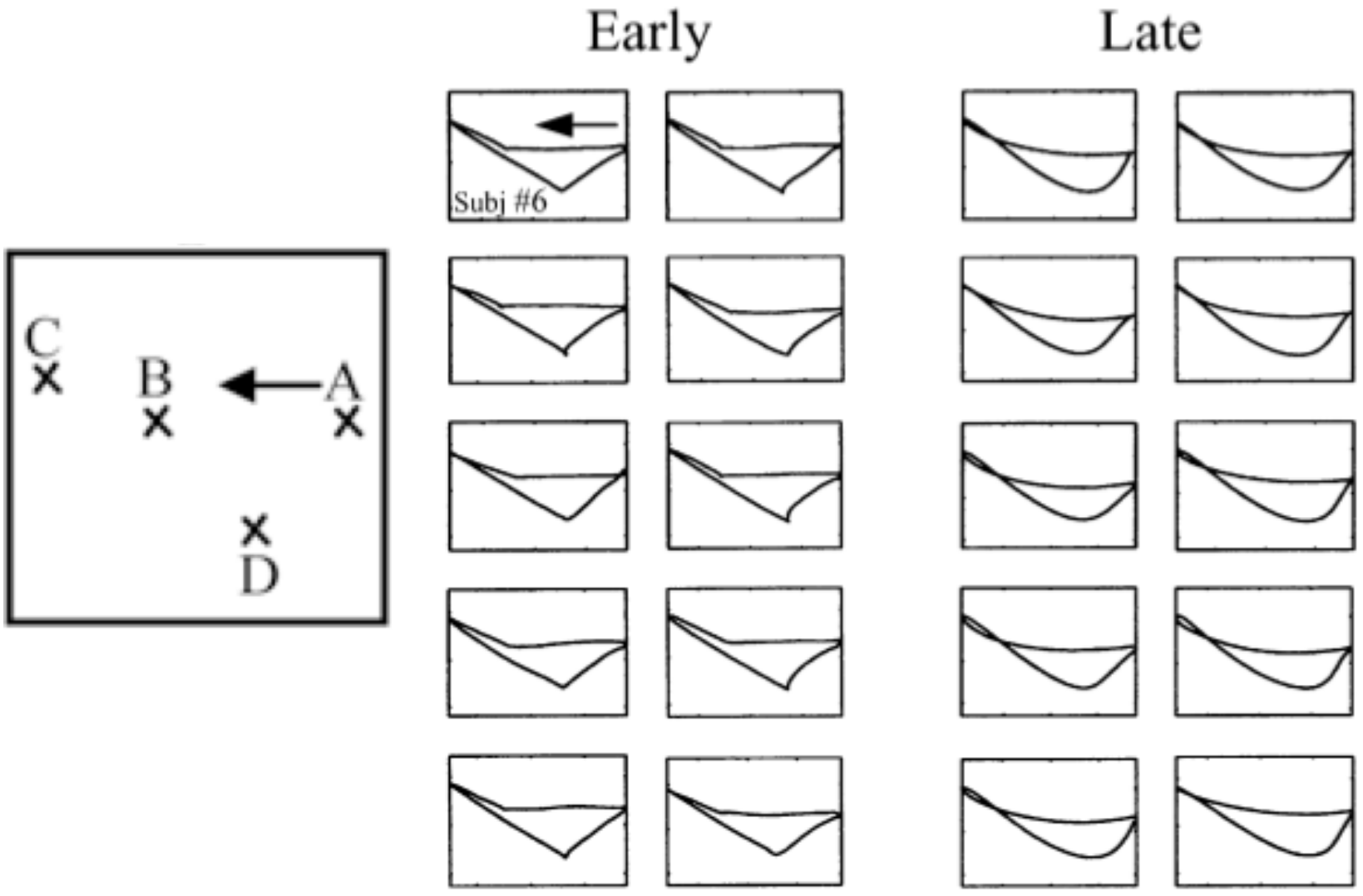
SLOW LEARNING

- Slow learning occurs between training sessions
- It is dependent on sleep
- It involves changes in the representation of the sequence in the motor cortex (M1)

CHUNKING

- One way that the representation could be changed is by "chunking"
- There is where lower-level primitives are combined in a hierarchical way (e.g. Sosnik et al., 2004)

CHUNKING



WAYS OF MANIPULATING PRACTICE

- There are several ways of performing training that are known to affect learning performance. These include:
  - sleep
  - augmented feedback
  - massed practice

CONSOLIDATION AND INTERFERENCE

- Consolidation occurs a few hours after practice, where skills are processed, changed and strengthened in memory
- Consolidation refers to
  - improvement in the skill off-line, between practice sessions
  - increase in stability of memory resulting from training making it no longer susceptible to interference
- Both aspects of consolidation can be measured in the lab using motor skill learning
- The consolidation process can be interfered in most subjects
- One way of doing this is learning a similar sequence 30-90 minutes after learning the initial sequence

VARIANCE AND LEARNING

- In the finger opposition task, subjects are required to make many decisions about how to perform the sequence
- The task is redundant at many levels, i.e. there are many ways to perform the task, for example
  - contribution of the fingers vs. the thumb to the movement
  - magnitude of the finger movements
  - relative timing
  - posture of the hand

VARIANCE AND LEARNING

- In addition, there is variability inherent in any movement
- Source of variability include:
  - noisy and delayed sensory feedback
  - noisy motor commands
  - variable relationship between motor command and outcome, due to the environment

VARIANCE AND LEARNING

- With motor learning, the amount of variance is reduced
- However, at early stages of motor learning, exploration of solutions is useful for improving learning
- Recent studies (e.g. Wu et al., Nature Neuroscience 2014) have shown that higher levels of task-relevant motor variability predict motor learning ability
- This corresponds with the notions of action exploration, from reinforcement learning, i.e. variability is regulated to improve learning

GOALS OF THE STUDY

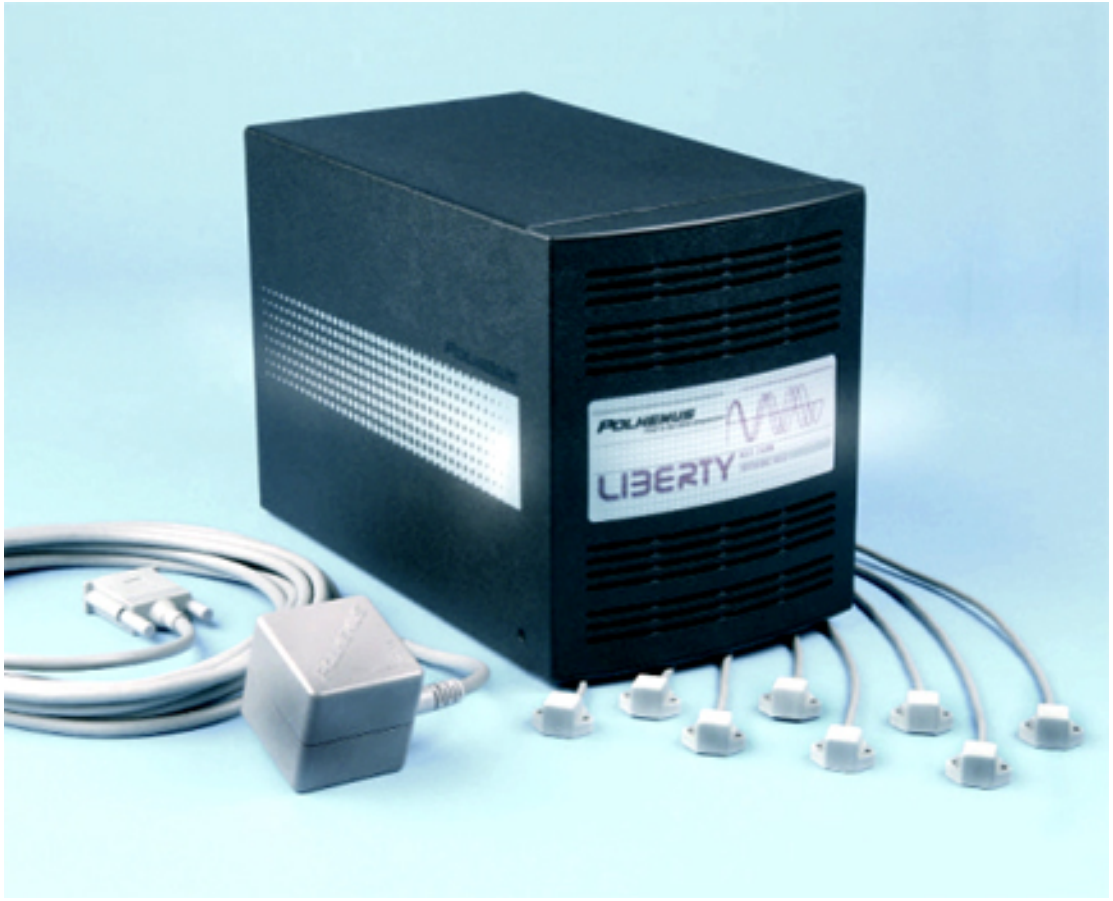
There were several goals for this study:

- How, in terms of kinematics, did subjects improve their performance
- What is the effect of interference on behavioral measures (number of sequences) and kinematic measures?
- Can we predict learning outcomes from early variability?

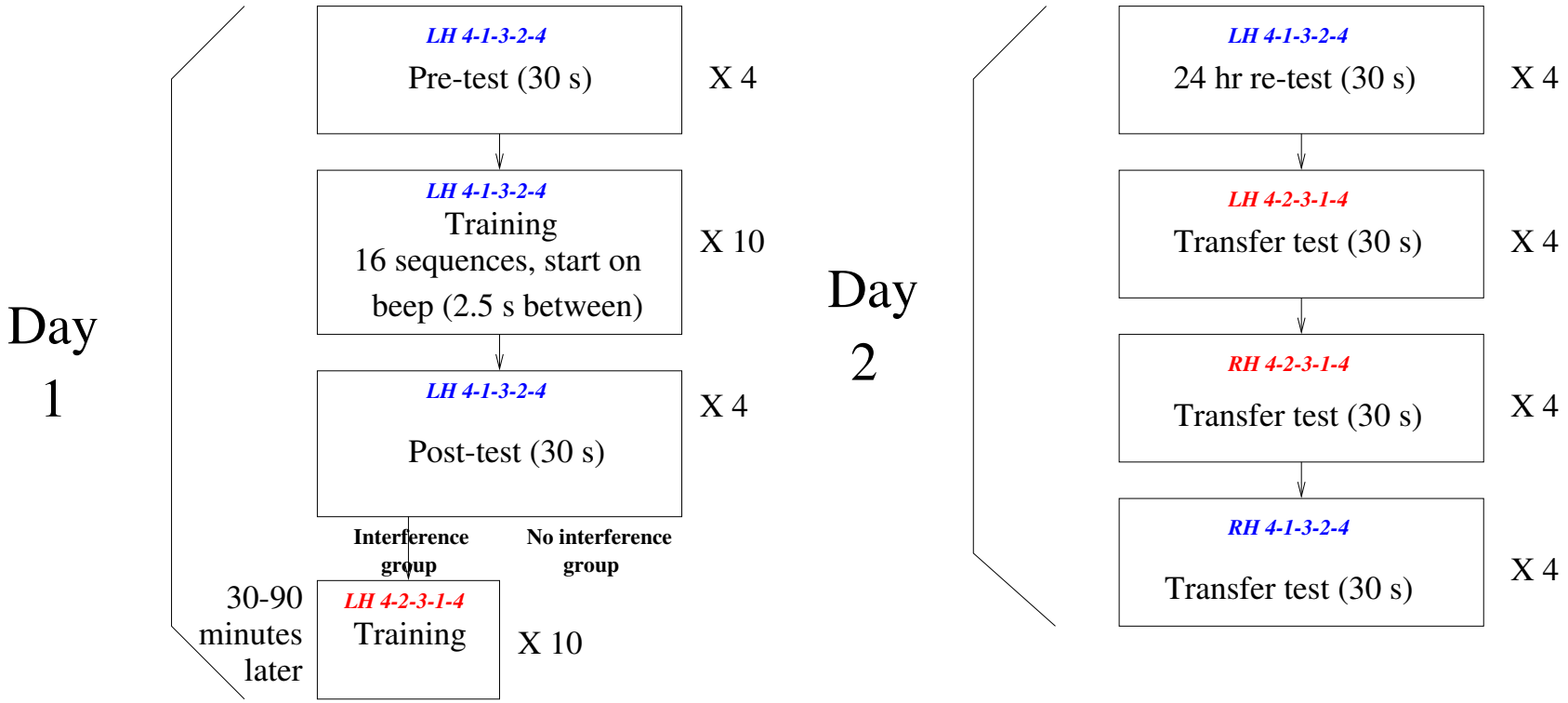
METHODS

- We used the sequence production task used in many previous studies
- *Right* handed subjects touch the fingertip with the thumb of the *left* hand in a specified order (4-1-3-2-4)

- We recorded the trajectories of the fingertips using a magnetic motion capture system (Polhemus Liberty) at 240 Hz

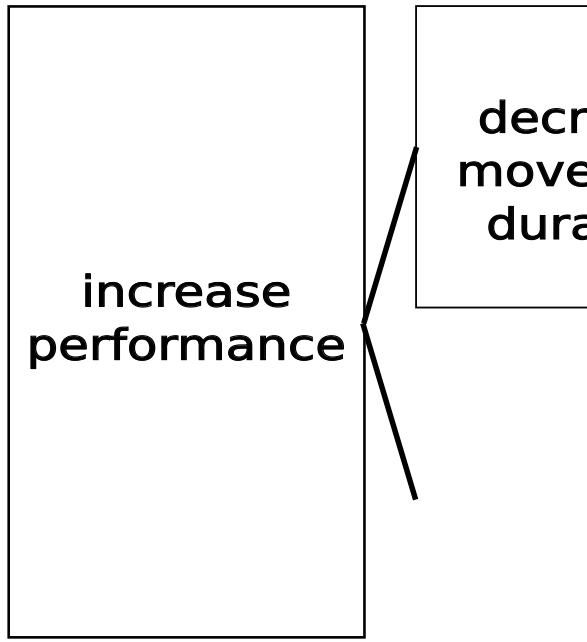


PROTOCOL



- Two groups:
  - No-interference group: Performed pre-test, training, post-test and 24 hr tests
  - Interference group: In addition, 30-90 minutes after the pre-test, the subjects learned another sequence (4-3-2-1-4)

DECOMPOSITION OF IMPROVEMENT



DATA ANALYSIS

- Analyze the behavioral data - number of sequences, number of error
- Decompose the improvement as described
- Improvement is defined as the relative difference compared to the first test:

$$I_j = \frac{S_j - S_1}{S_1} = \frac{S_j}{S_1} - 1 = \frac{\frac{D}{T_j}}{\frac{D}{T_1}} = \frac{T_1}{T_j} - 1$$

I_j = improvement, S_j = number of sequences,
D = time available (30 seconds), T_j = average time taken

DATA ANALYSIS

- The time taken for each sequence can be divided into the time for the movements (t_{mj} and the gap t_{gj})

$$T_j = t_{mj} + t_{gj}$$

- The improvement can then be decomposed into the part due to reduction in movement time (I_{mj}) and the reduction in gaps (I_{gj}):

$$I_{mj} = \frac{t_{m1} - t_{mj}}{T_j}$$

$$I_{gj} = \frac{t_{g1} - t_{gj}}{T_j}$$

- We note that the time for the gaps can become negative (due to coarticulation)

DATA ANALYSIS

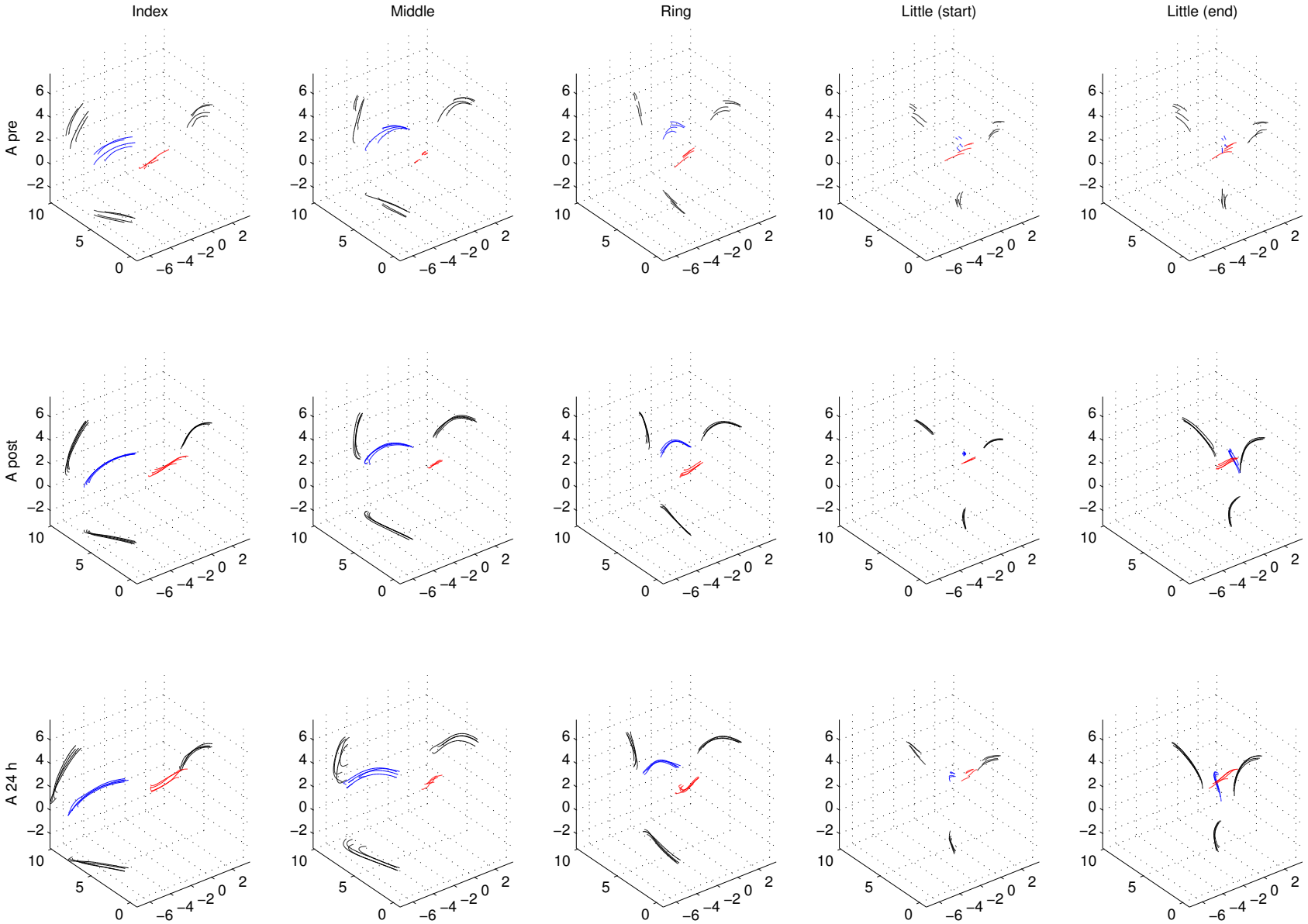
- The improvement in movement time can be further decomposed into a reduction of the amplitude or an increase in the peak velocity

$$I_{pj} = \frac{t_{m1}\left(1 - \frac{P_j}{P_1}\right)}{T_j}$$

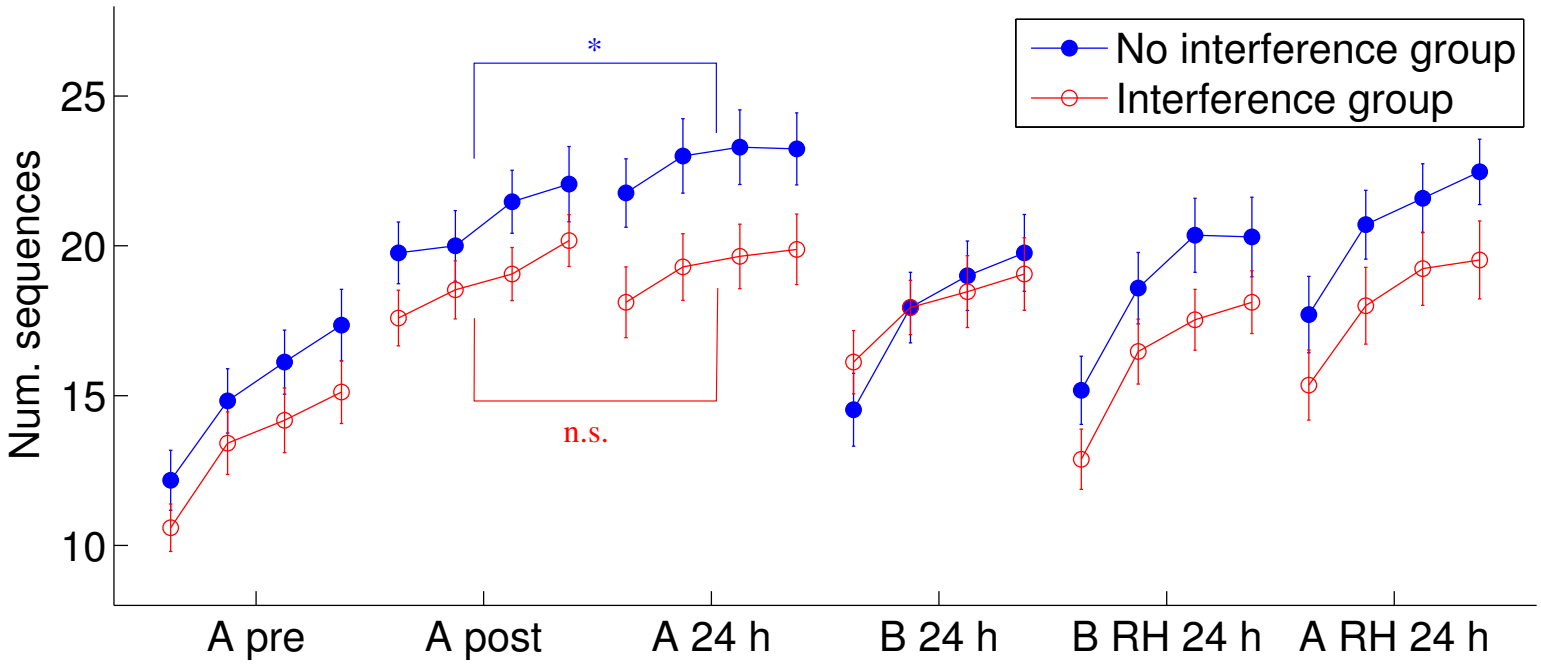
$$I_{aj} = \frac{t_{m1}\left(1 - \frac{A_1}{A_j}\right)}{T_j}$$

P_j is the peak velocity, A_j is the amplitude

SAMPLE MOVEMENTS

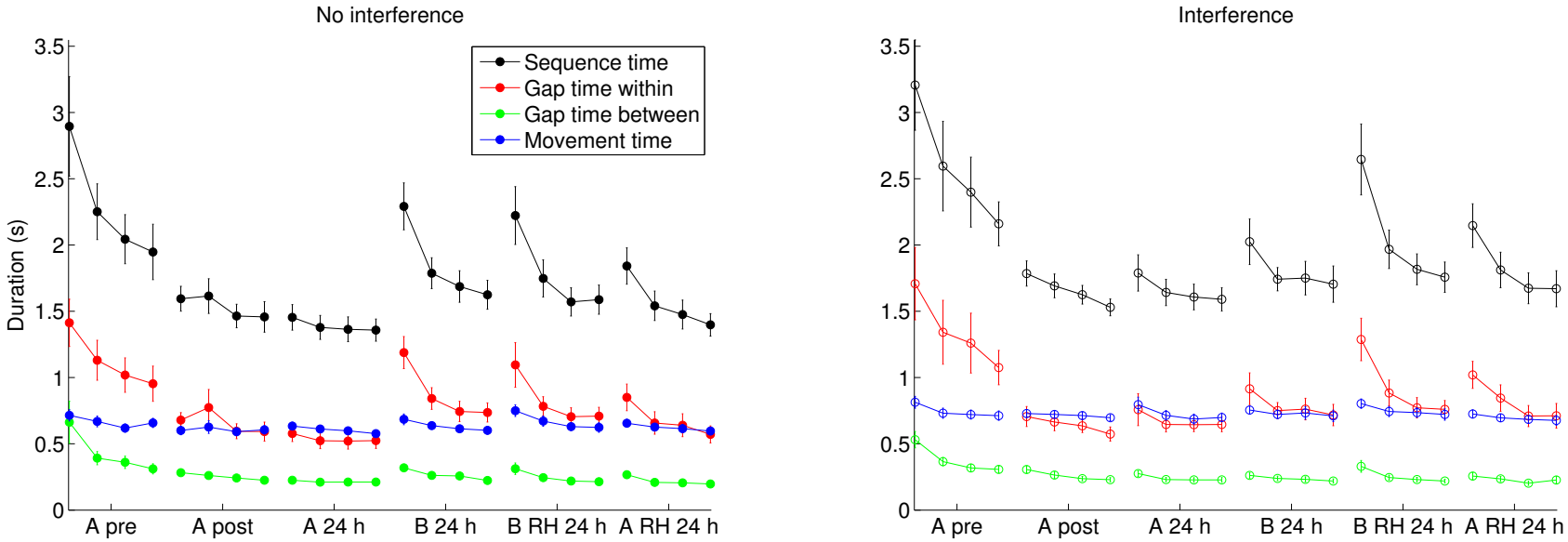


RESULTS



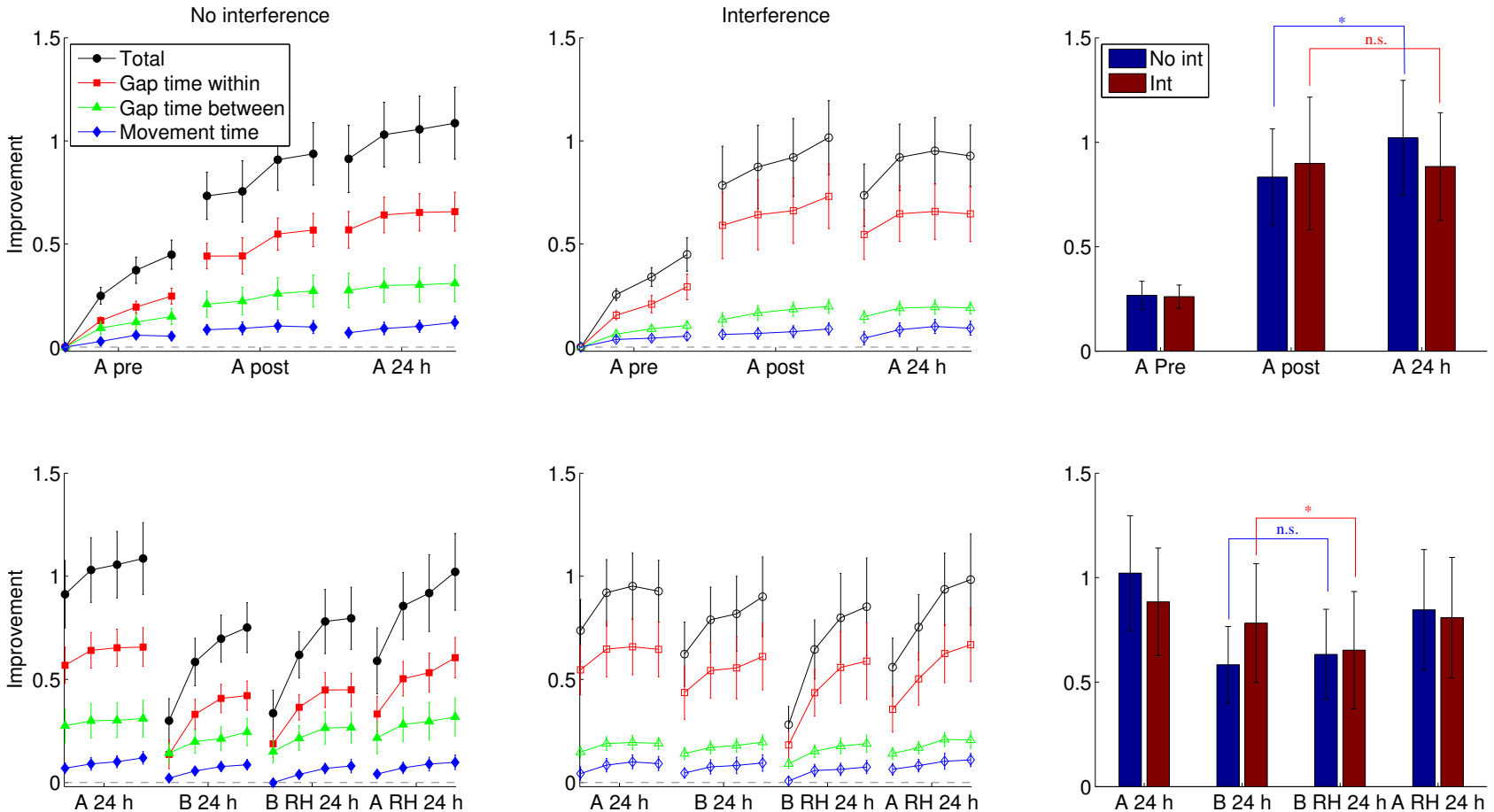
- Both training protocols resulted in significant improvements during training
- There was significant consolidation only for the no-interference group

DECOMPOSITION OF SEQUENCE TIME



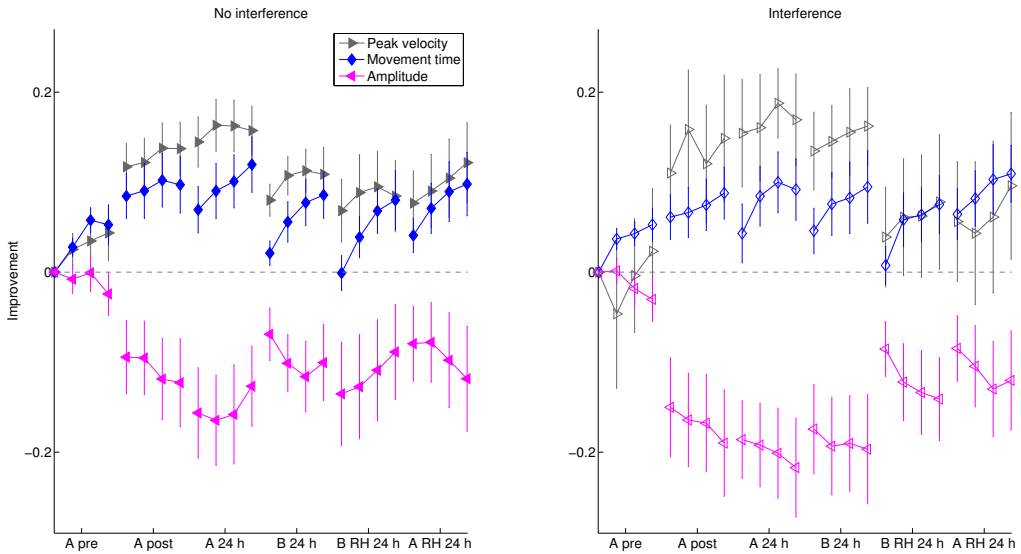
- Movement time is initially about $\frac{1}{3}$ of the sequence time
- While the gap times decrease, there is almost no change in the movement time

RESULTS



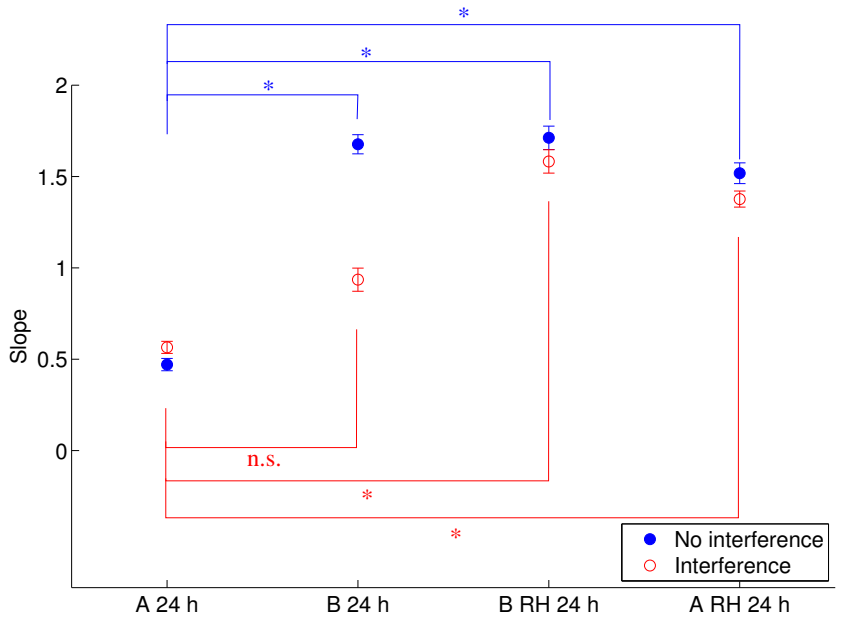
- Most of the improvement came from reduction in the gaps
- Gaps within sequences accounted for more improvement then gaps between sequences

RESULTS - IMPROVEMENT IN MOVEMENT TIME



- Overall, there is almost no change in overall performance due to changes in movement
- Decomposing the improvement into velocity and amplitude shows significant changes
- In general, the peak velocity increased
- The amplitude also increased (i.e., negative improvement)
- These two effects approximately canceled out

RESULTS - NOVELTY EFFECT



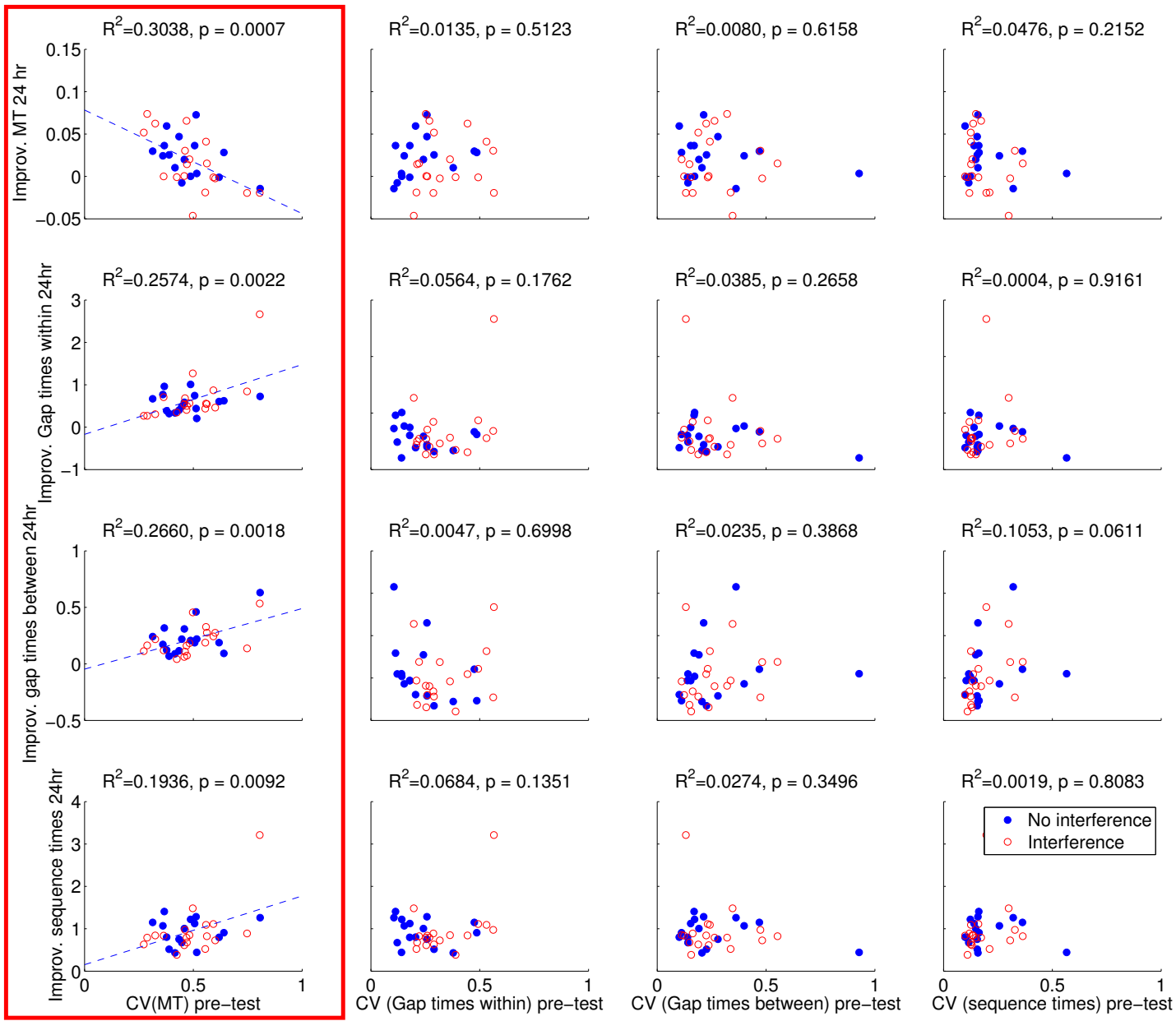
- The novelty effect is quantified by the slope of performance within the 4 repetitions of a test / re-test
- If the sequence is novel, performance will likely improve significantly (i.e. large slope). If it is not novel, the improvement (slope) will be small
- The second sequence was not novel for the interference group, showing that they did learn the second sequence

DOES VARIANCE PREDICT IMPROVEMENT?

- Often the standard deviation increases approximately linearly with the mean for movement-related measures
- This may cause spurious correlations to occur if we compare standard deviation to the mean
- Instead we will use the coefficient of variation (CV), which is the standard deviation divided by the mean

$$c_v = \frac{\sigma}{\mu}$$

DOES VARIANCE PREDICT IMPROVEMENT?



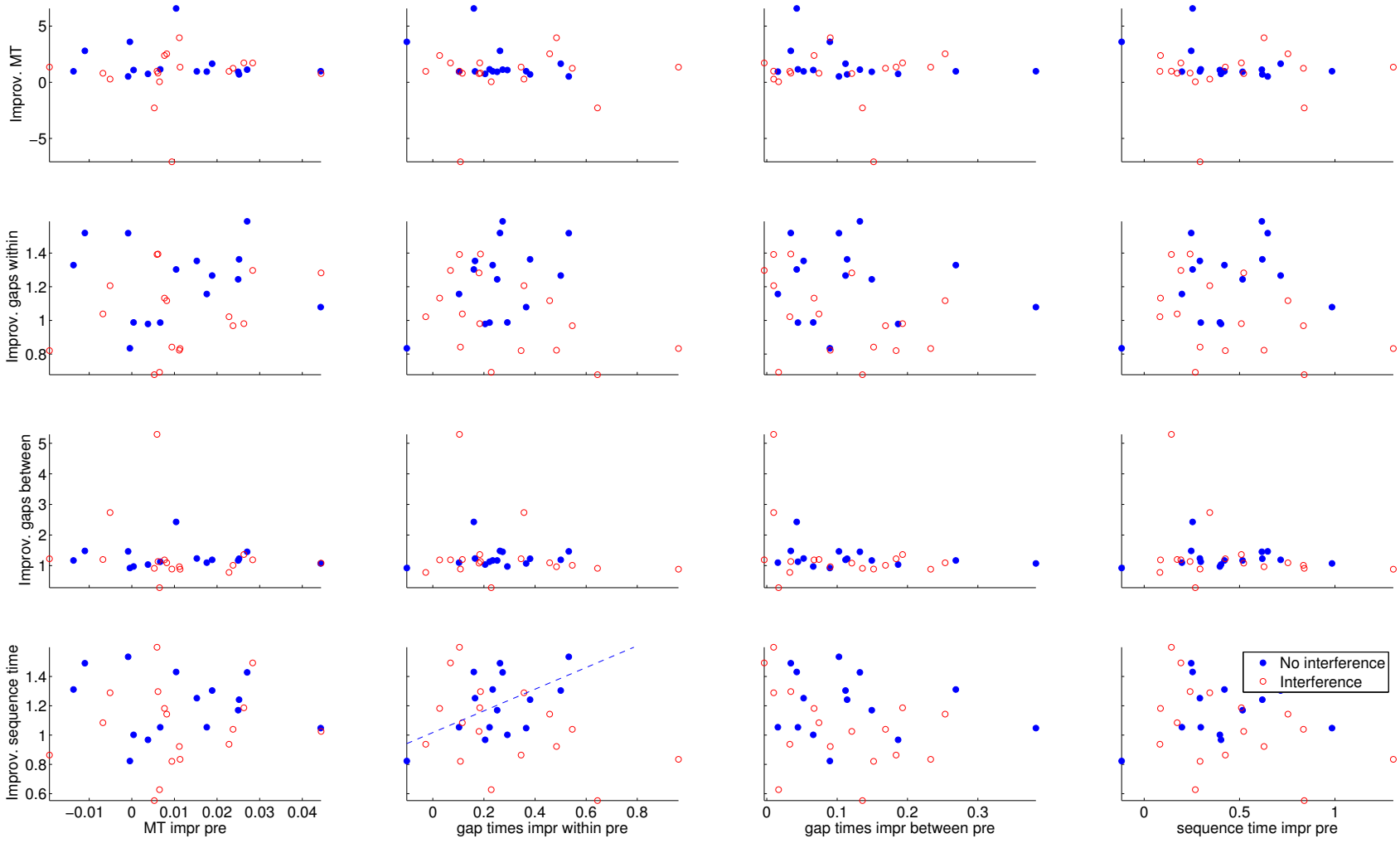
DOES VARIANCE PREDICT IMPROVEMENT?

- We observe that the CV of movement time in the first pre-test (30 s) predicts the improvement in sequence time and gap times at post-test and at 24 hr
- There is a small negative correlation of movement time improvement with movement time CV
- The CV of gap time or sequence time does *not* predict improvement
- The CV predicts improvement at post-test or 24 hr, but not the consolidation change

What does predict consolidation improvement?

- Does improvement in the first session predict the amount of improvement with consolidation?
- We found that only the improvement in gap times within a session predicts consolidation improvement of sequence time, but only for the no-interference group
- No other correlations were significant

WHAT DOES PREDICT CONSOLIDATION IMPROVEMENT?



SUMMARY

- As expected, learning a second sequence shortly after the first interfered with the consolidation of the first sequence
- The effects of interference were *not* the same for all aspects of the movement
- The abstract, organization driven process of determining the gaps between movements *was* affected by interference
- The sensory feedback driven timing of individual movements *was not* affected by interference
- An absence of change in movement time does not mean learning did not take place in terms of the movement itself
- Rather, robust changes were seen in terms of the movements, but the changes in velocity and amplitude were masked

SUMMARY

- While movement time did not show large changes with learning, the CV of movement time in the first 30s pre-test predicted the improvement during fast learning (on the first day)
- CV of MT did not predict consolidation gains
- The improvement in gaps did predict the consolidation gains for the no-interference group

Conclusions

- Interference is naturally present in almost any ecological setting (e.g. sensory distractors, competing experiences)
- Their influence should be considered in the time course of learning in typical and clinical populations
- We note that the effect of interference differs depending on the type of learning
- Optimization of timing of motor components seems to be affected by interference
- Biomechanical or sensory-feedback related optimization is likely to be interference immune
- Variance during some aspects of training are correlated with the amount of improvement. It is currently unknown if artificially increasing variance will lead to greater improvement

THANKS

- Co-investigator: Maria Korman (Dept. Occupational Therapy, Haifa University)
- Research assistant: Maayan Ben Nun, for performing the data collection