Models of Perception and Action
Cordula Vesper
BSc in Cognitive Science
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Motion tracking and analysis

Topics for today

In this class, we will look at bodily movements and discuss how we can measure and analyze the kinematics of action performance.

Looking back and ahead

Where do we stand?

- Perceptual decision making, esp. signal detection theory
- Principles of movement planning and performance, esp. internal forward and inverse models, end-state planning
- Interactions between perception, action and cognition, esp. Ideomotor theory
- 2-d movements, esp. mouse tracking

What is coming?

- 3-d movements and analysis parameters
- Interoception and sense of pain
- Social modulations of perception and action

Instructor classes

- Practical exercises on movement trajectories
- Theoretical discussions
- Virtual Reality workshop (9.5.)
- No class next week (4.4.)

Today's roadmap

Step 1: Specifying research question

Step 2: Designing task and procedure

Step 3: Deciding on measurement technique(s)

Step 4: Checking data quality

Data collection

Step 5: Data preprocessing

- Inspection and corrections
- Filtering
- Velocity and acceleration

Step 6: Parameter extraction

Statistical analysis

Step 7: Interpreting kinematic parameters wrt to research question

Example for today: Vesper, C., Schmitz, L., & Knoblich, G. (2017). Modulating action duration to establish non-conventional communication. *Journal of Experimental Psychology: General*, *164*(12), 1722–1737.

Step 1: Specifying research question

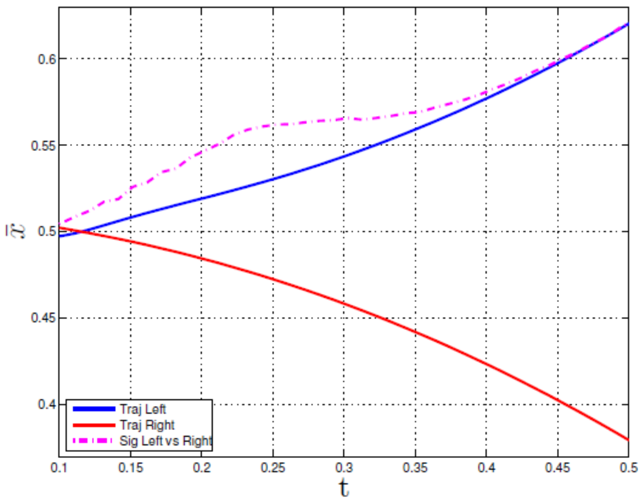
If no other means of communication are available would participants deviate from efficient action performance to provide information to a task partner?

To be considered:

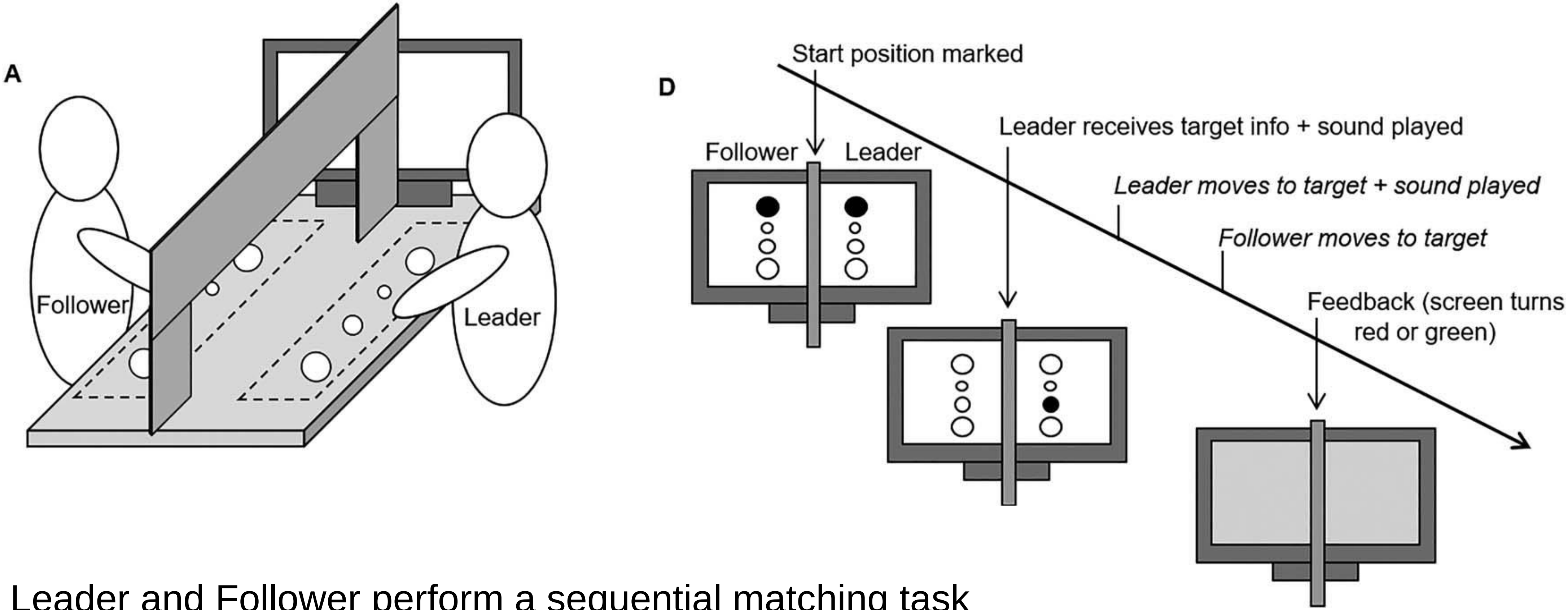
- What do we mean with “efficient” performance?
- How can we measure deviances from such efficient performance?

Signaling / sensorimotor communication

“We formalize signaling in terms of parametrizable deviations from the action's optimal trajectory so that the signaling action retains its pragmatic goal (e.g., grasping an object) but the changes in the kinematic parameters are informative of the performer's action choice.” Pezzulo et al., 2017, p. 3

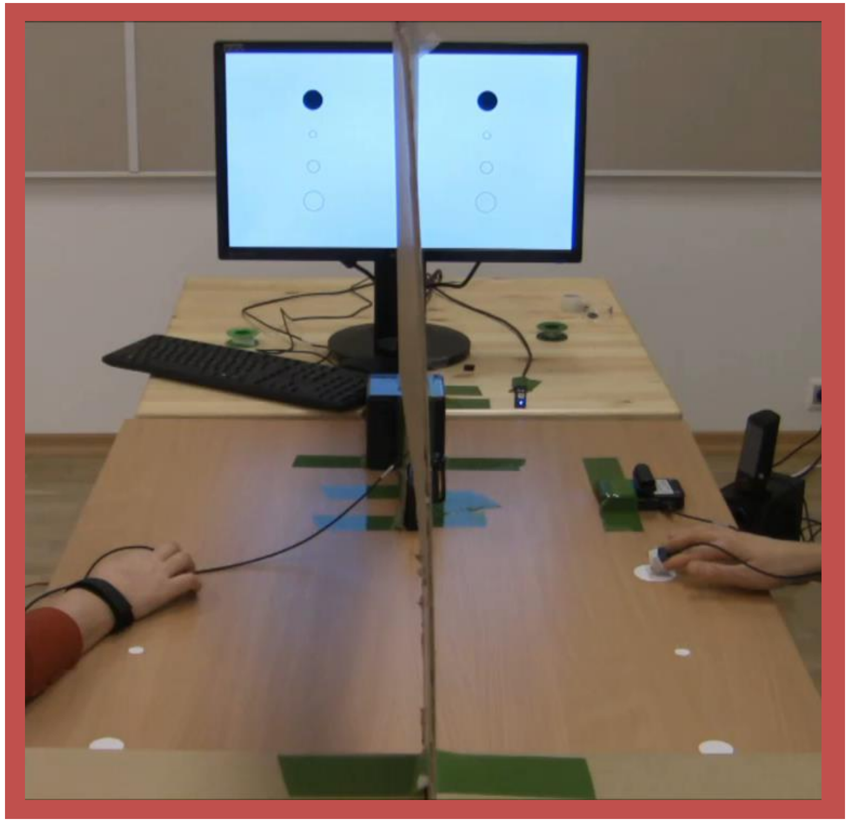


Step 2: Designing task and procedure



- Leader and Follower perform a sequential matching task
- Leader has task-relevant information, Follower not

Step 2: Designing task and procedure

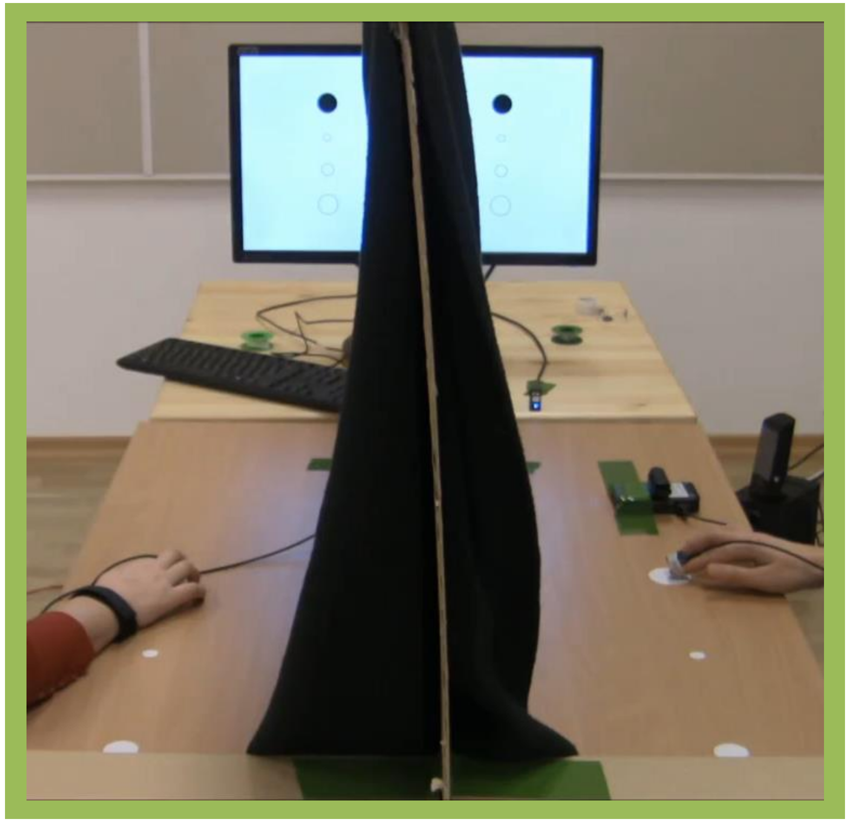


Conditions:

Informative vision

Informative pitch

Uninformative



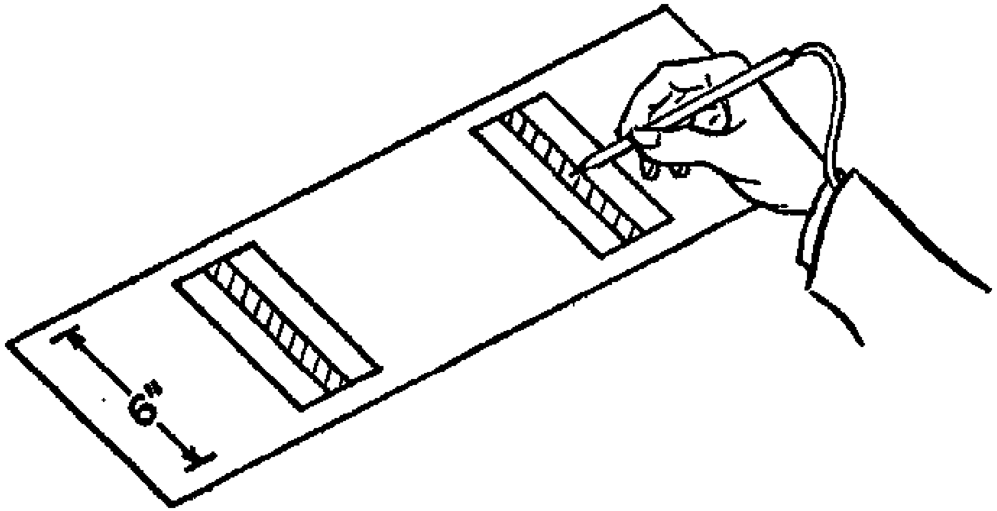
Fitts' law

A movement law describing a tradeoff between speed and accuracy in speeded movements

$$\boxed{MT = a + b \times ID}$$

Index of Difficulty (ID) = relationship of movement amplitude ('distance') and target width ('width')

$$\boxed{ID = \log_2(2A/W)}$$



First study by Paul Fitts in 1954

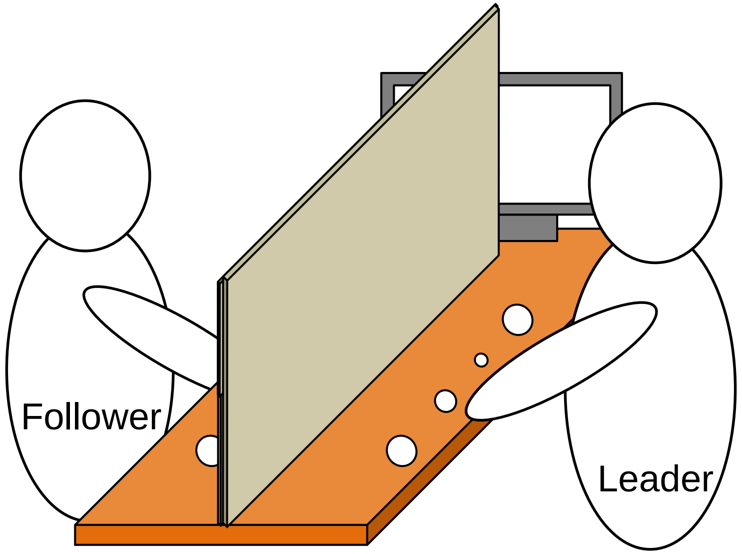
FIG. 1. Reciprocal tapping apparatus. The task was to hit the center plate in each group alternately without touching either side (error) plate.

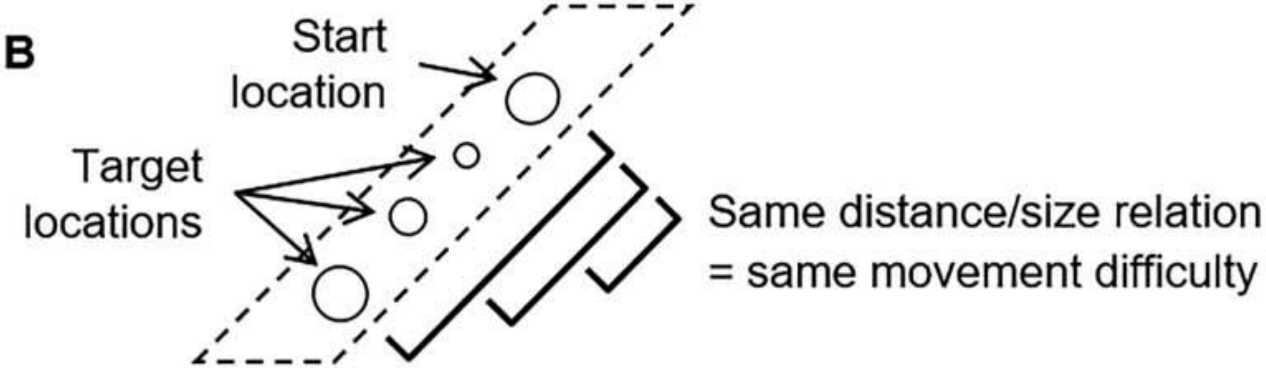
Making use of Fitts' law

Fitts' law helps to make predictions about movement timing

→ Way to quantify 'efficient' movement

If we vary target size according to Fitts' law, efficient (speeded) performance to the 3 targets should be equal





A	W	ID
20	1.6	4.64
40	3.2	4.64
60	4.8	4.64

Step 3: Deciding on measurement technique(s)

Why use motion tracking?

- Quantify various performance parameters that are hidden e.g. when collecting button-press responses
- Precise analyses of movements, e.g. in sports sciences and rehabilitation research
- Measure task-specific deviations from ‘typical’ performance
- Allow online control of experimental procedure based on task performance
- Use more realistic action tasks (in contrast to virtual movements etc.)
- Control that no movements happened, e.g. in infant research
- Detect early neuropsychological issues, e.g. in Autism

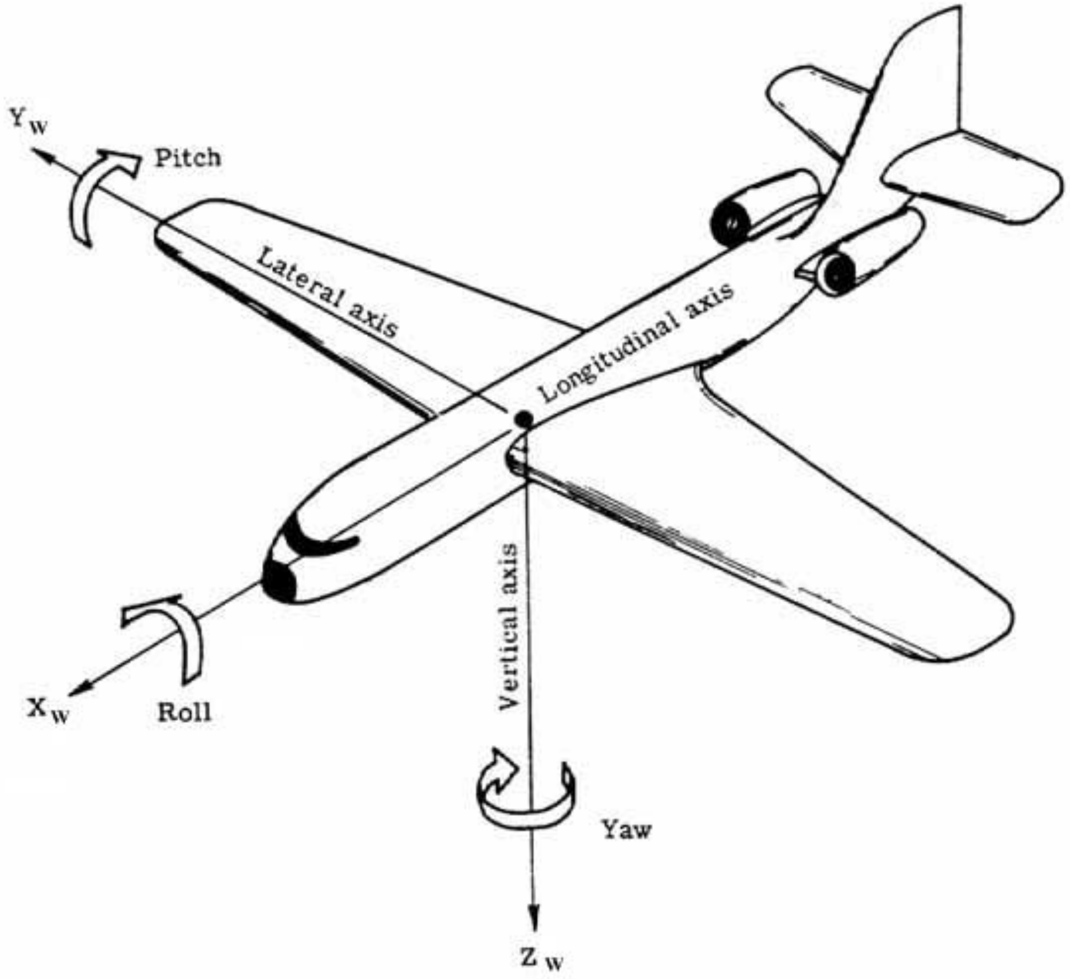
Motion tracking refers to all kinds of techniques to record dynamic behavior in space.

Step 3: Deciding on measurement technique(s)

Degrees of freedom

An object (or body) has six degrees of freedom in space: Movement on the x, y and z axis and rotation about these axis.

Different measurement techniques allow measuring movement on some or all of these dimensions.



Step 3: Deciding on measurement technique(s)

Decisions to make:

- Which parts of the body (single limbs, a finger, an arm, the whole body)
- What spatial coverage (one or multiple sensors, placement of sensors)
- What technology (optical, magnetic, gravity-based), what gets measured (position, orientation, acceleration …)
- What temporal and spatial resolution (high, low)
- How prone to occlusions and other noise
- How to ensure participants’ comfort and safety (wearable, not disturb natural body movements and task performance)
- How portable (stationary systems, more flexible systems, or simple devices like mobile phones)
- Many more practical aspects: price range and availability, software availability, ease of use, room requirements etc.

Tracking systems

Specific movement tracking devices

OptoTrac, Vicon, Qualisys

Polhemus

Video camera based

Sensor types

Sensors (w/o cables)

Body suits

Sensor gloves

Commercial performance trackers

Wearable sensors (google watch etc.)

Objects with built-in sensors (mobile phones)

Gaming technology

Kinect, Wii

Virtual Reality

Motion data usually require preprocessing; afterwards they can be treated like any other data.

Tracking systems: Magnetic sensors

How does it work?

Source creates light magnetic environment

Sensors detect distortions due to movement

Advantages

Not so sensitive to occlusions

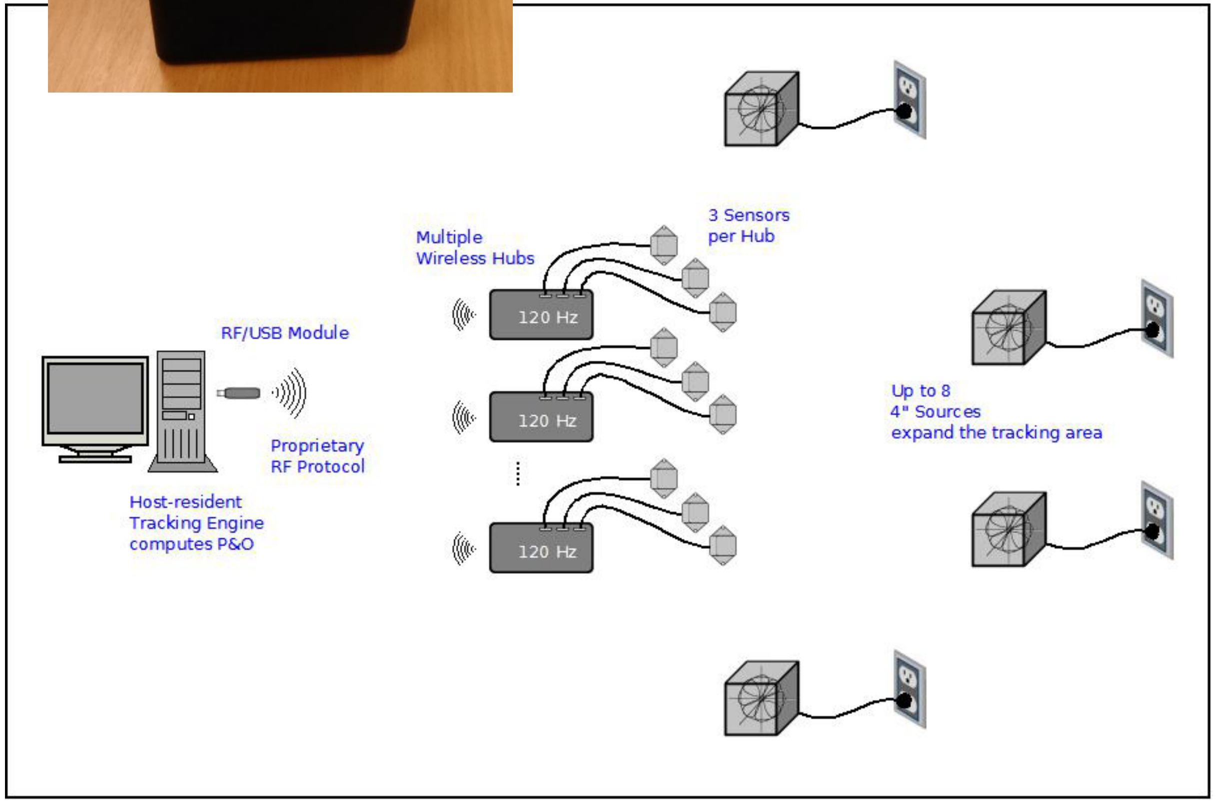
Flexible setup, portable

Disadvantages

Requires shielded environment

Difficult to combine with other methods, e.g. EEG

Example: Polhemus G4 system



Tracking systems: Optical sensors

How does it work?

Active or passive sensors are picked up with a system of cameras

Other systems, e.g. Microsoft Kinect

Calibration procedure to detect joints → extracts skeleton based on movement contingencies

Common advantages

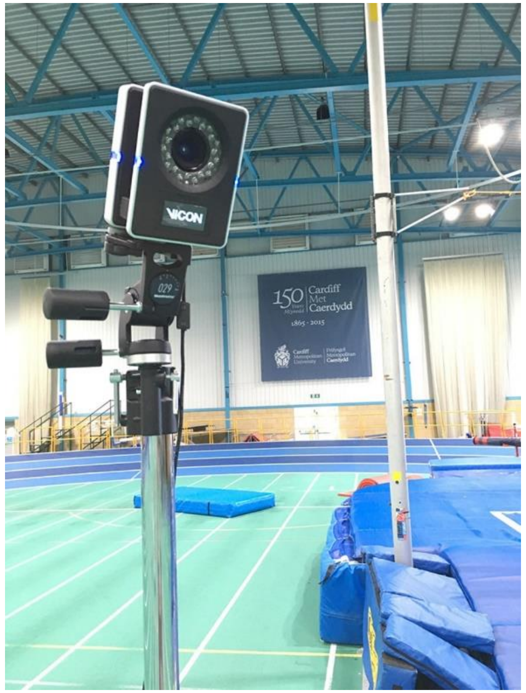
Stable signal

Large coverage

Common disadvantages

Prone to occlusions, requires many cameras

Normally requires fixed setup



Example: Vicon system

Tracking systems: Accelerometers

How does it work?

Inertia-based, measures force against gravity

Advantages

Does not require calibration

Position independent

Often easy to set up

Disadvantages

Does not inform about absolute spatial position

Examples

Smart watches

Mobile phones

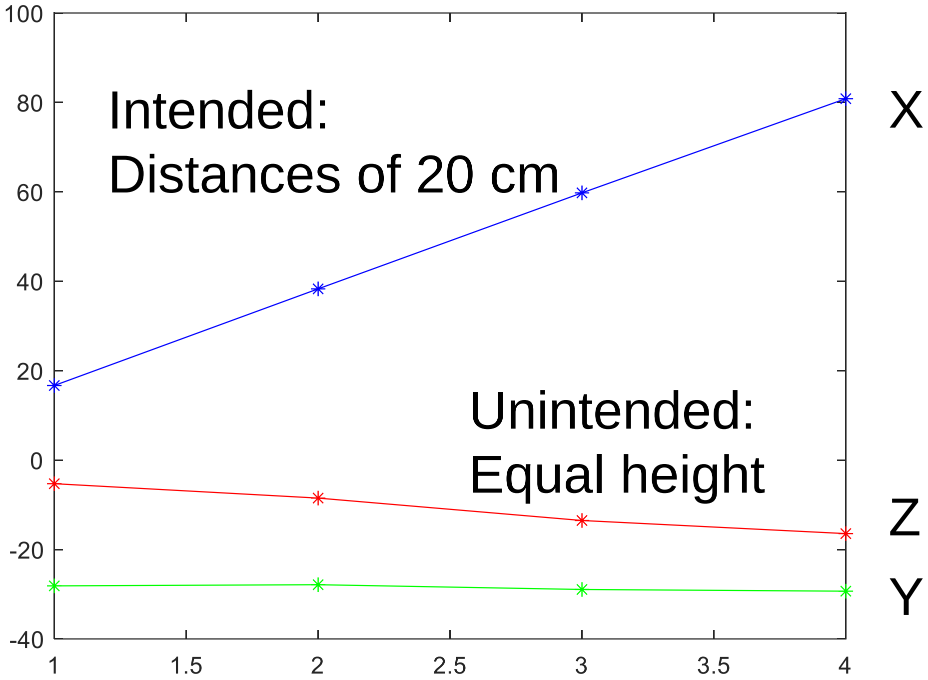
Specialized equipment, e.g. Swimtag

Example: Swimtag

Step 4: Checking data quality

We used a Polhemus magnetic motion tracking system

We calibrated the system before each part (= condition)



Testing for

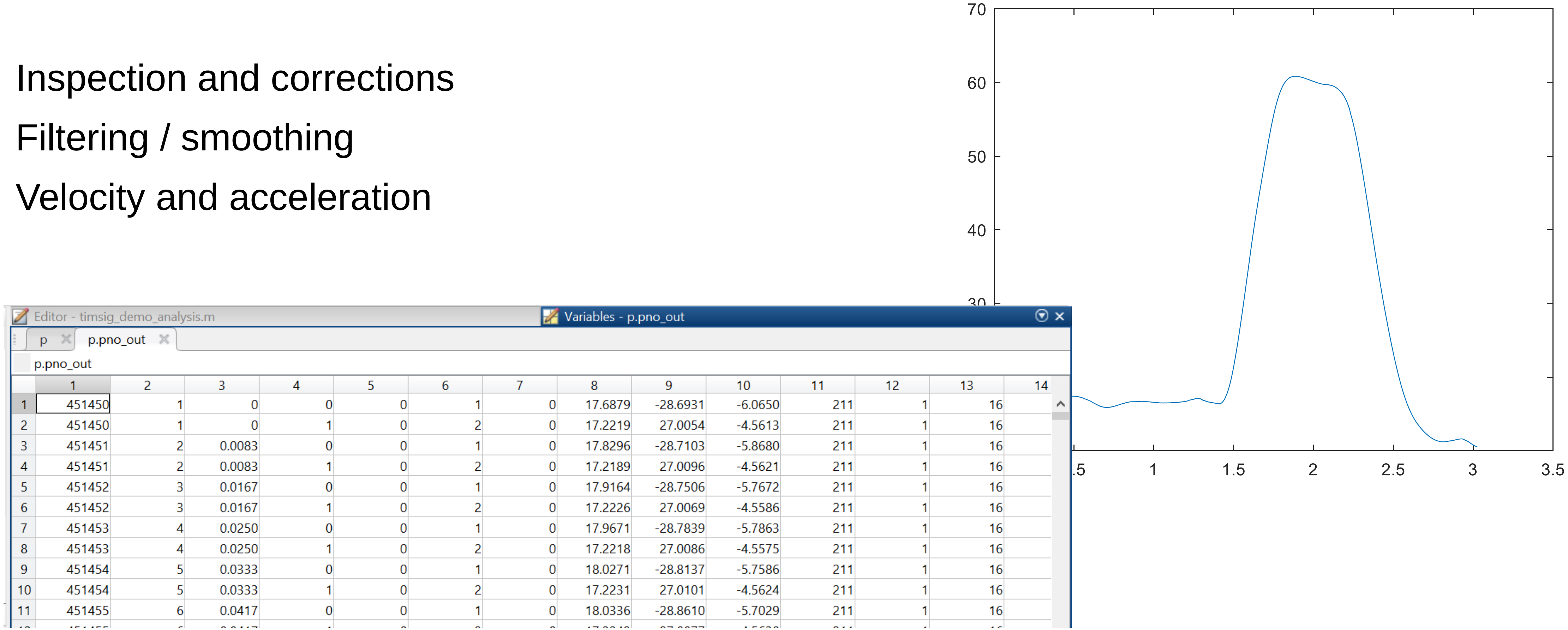
- Systematic distortions
- Missing data
- Other forms noise

Important to take time to minimize these potential problems before data collection!

Step 5: Data preprocessing

How do we extract information from raw movement data?

- Inspection and corrections
- Filtering / smoothing
- Velocity and acceleration



	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	451450	1	0	0	0	1	0	17.6879	-28.6931	-6.0650	211	1	16	
2	451450	1	0	1	0	2	0	17.2219	27.0054	-4.5613	211	1	16	
3	451451	2	0.0083	0	0	1	0	17.8296	-28.7103	-5.8680	211	1	16	
4	451451	2	0.0083	1	0	2	0	17.2189	27.0096	-4.5621	211	1	16	
5	451452	3	0.0167	0	0	1	0	17.9164	-28.7506	-5.7672	211	1	16	
6	451452	3	0.0167	1	0	2	0	17.2226	27.0069	-4.5586	211	1	16	
7	451453	4	0.0250	0	0	1	0	17.9671	-28.7839	-5.7863	211	1	16	
8	451453	4	0.0250	1	0	2	0	17.2218	27.0086	-4.5575	211	1	16	
9	451454	5	0.0333	0	0	1	0	18.0271	-28.8137	-5.7586	211	1	16	
10	451454	5	0.0333	1	0	2	0	17.2231	27.0101	-4.5624	211	1	16	
11	451455	6	0.0417	0	0	1	0	18.0336	-28.8610	-5.7029	211	1	16	

Inspection and corrections

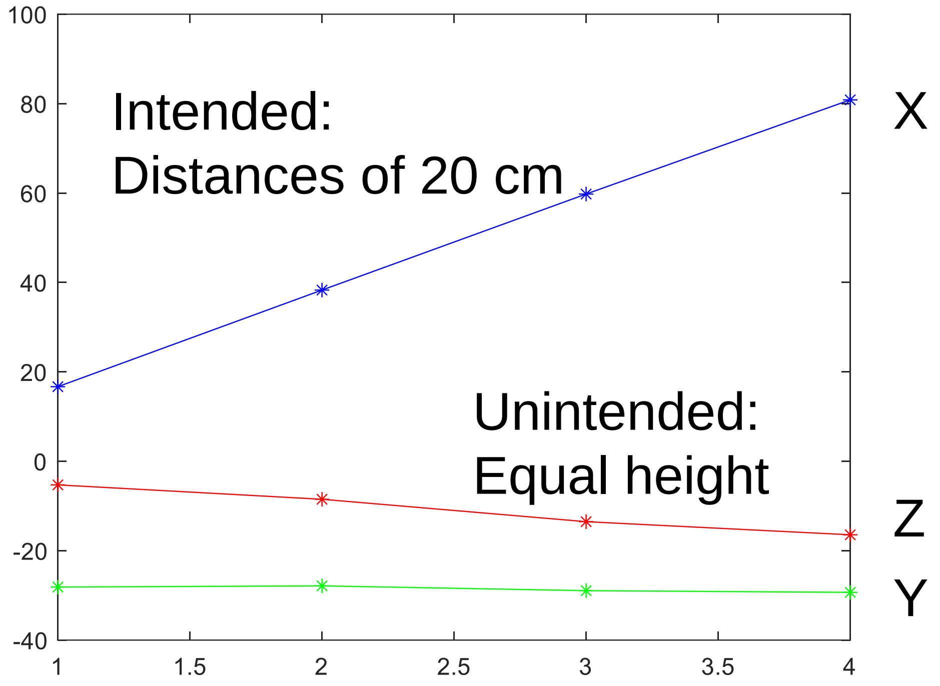
Missing data?

Systematic distortions?

Drift correction?

Cutting and segmentation needed?

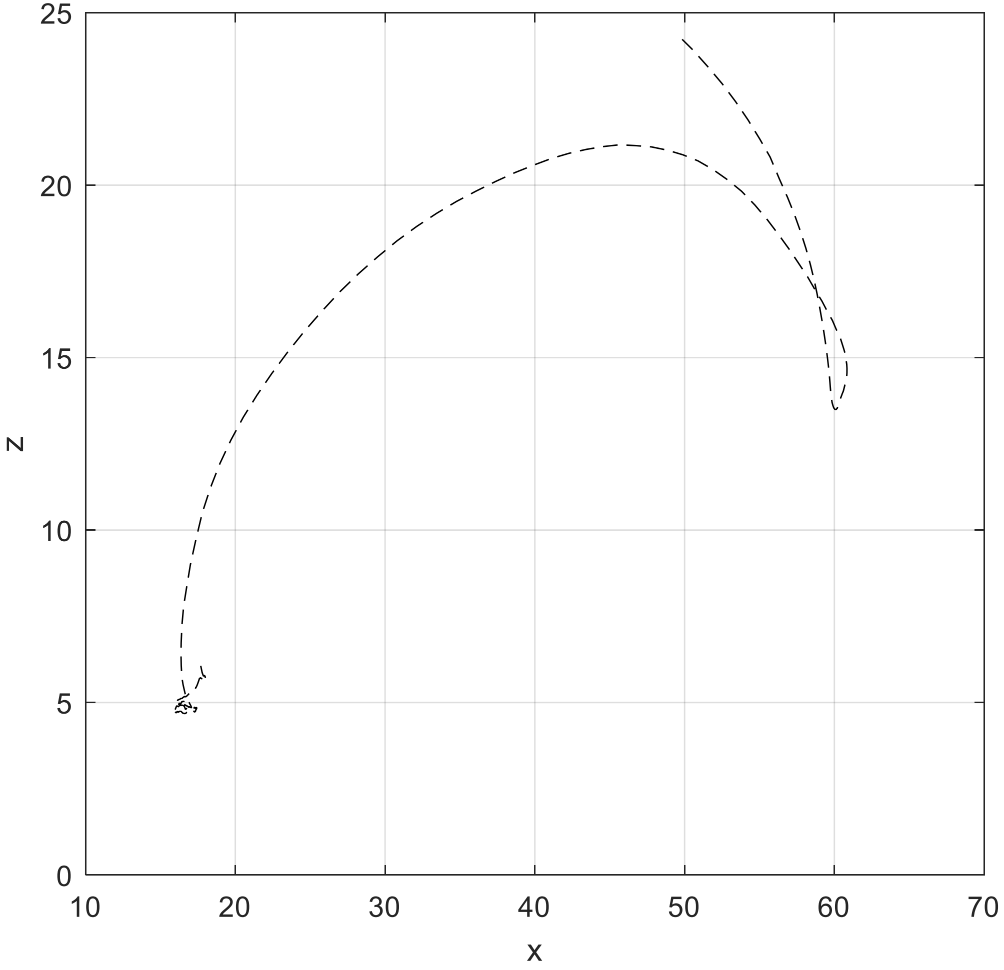
If an error is systematic, it can be possible to use a calibration procedure to measure it and then apply corrections.

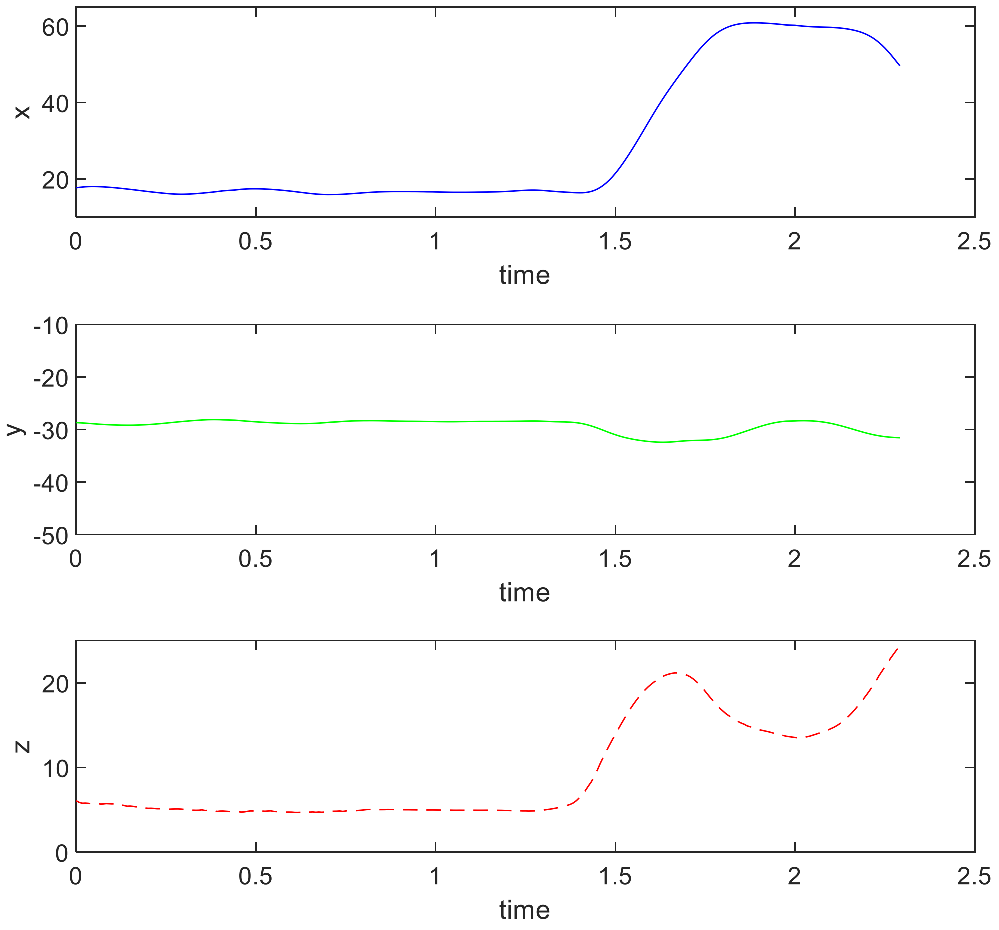


Example: Close-to-linear z deviation along the x axis.

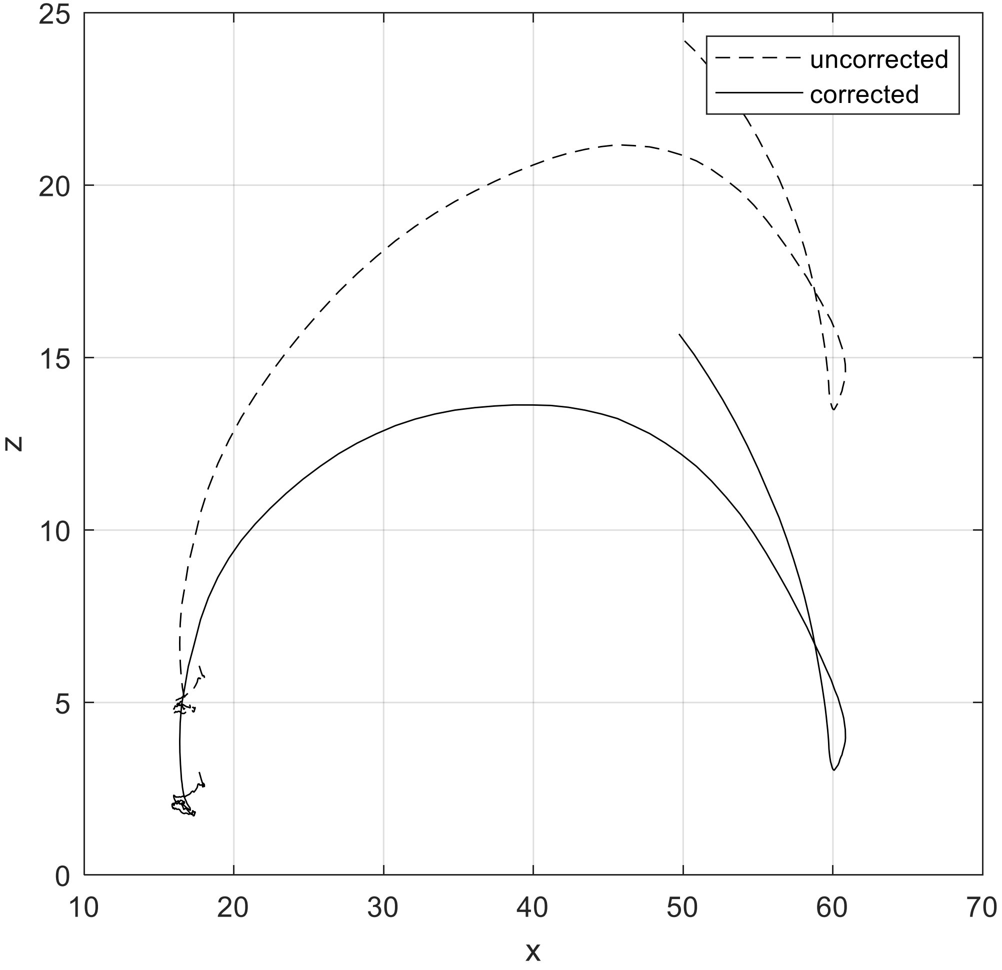
→ Apply linear correction using parameters extracted from calibration.

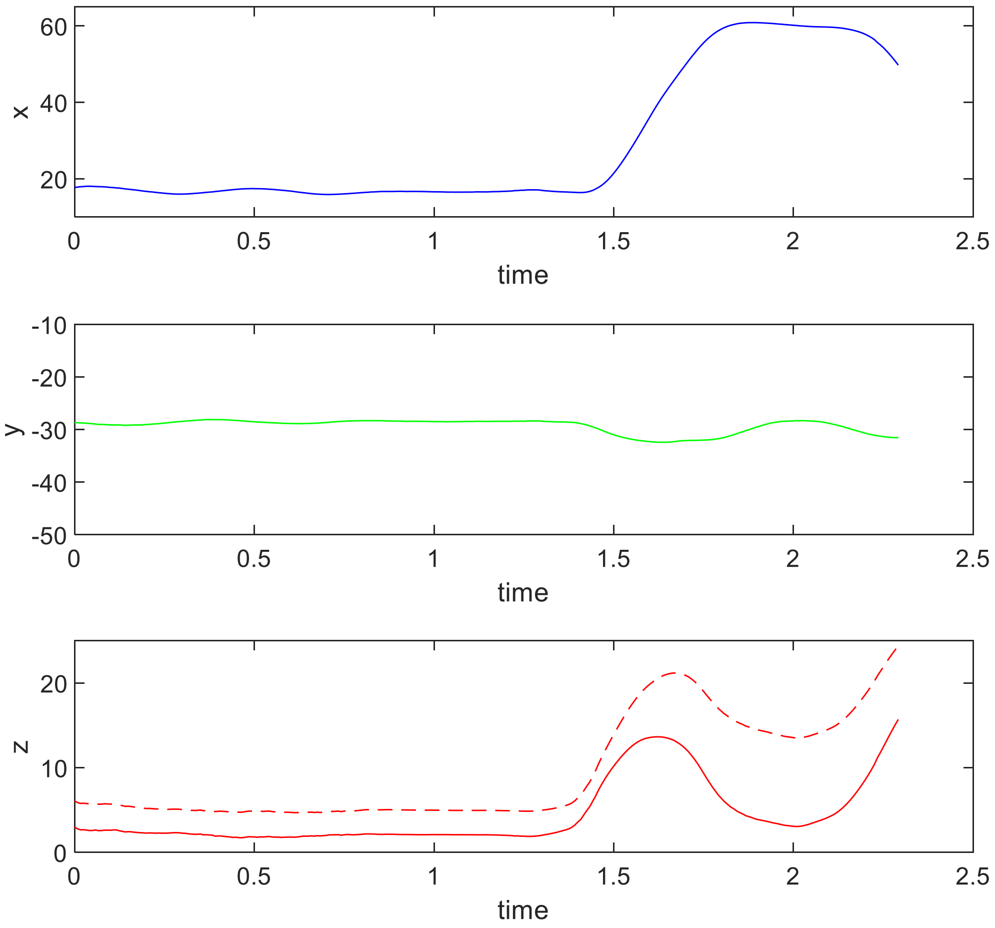
Inspection and corrections





Inspection and corrections





Filtering

Why filter?

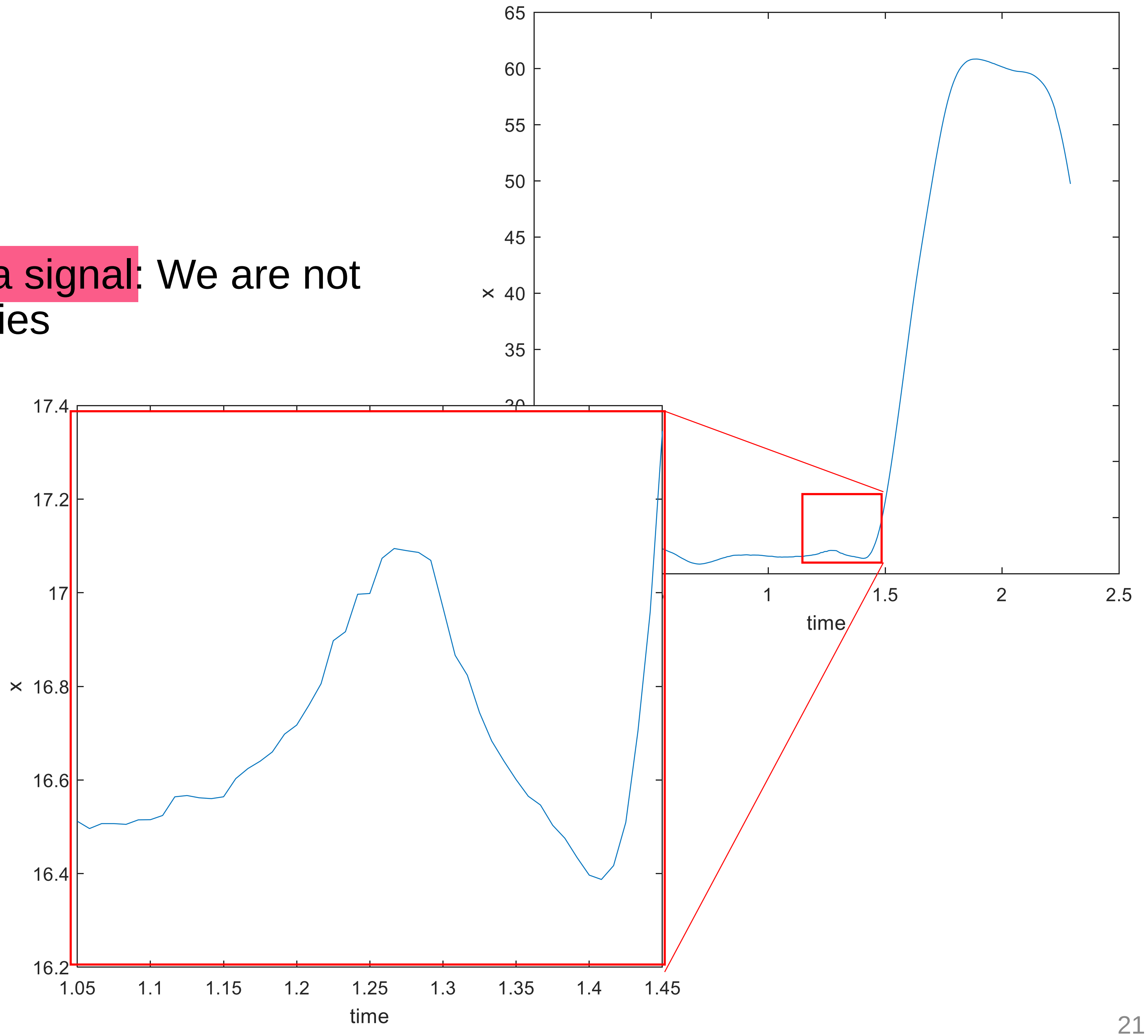
- Focus on the interesting part of a signal: We are not always interested in all frequencies
- Smoothen over missing values
- Discard noise (e.g. jitter)

Sources of noise

Noise within the motor system

Tracking equipment noise

Signal transmission noise

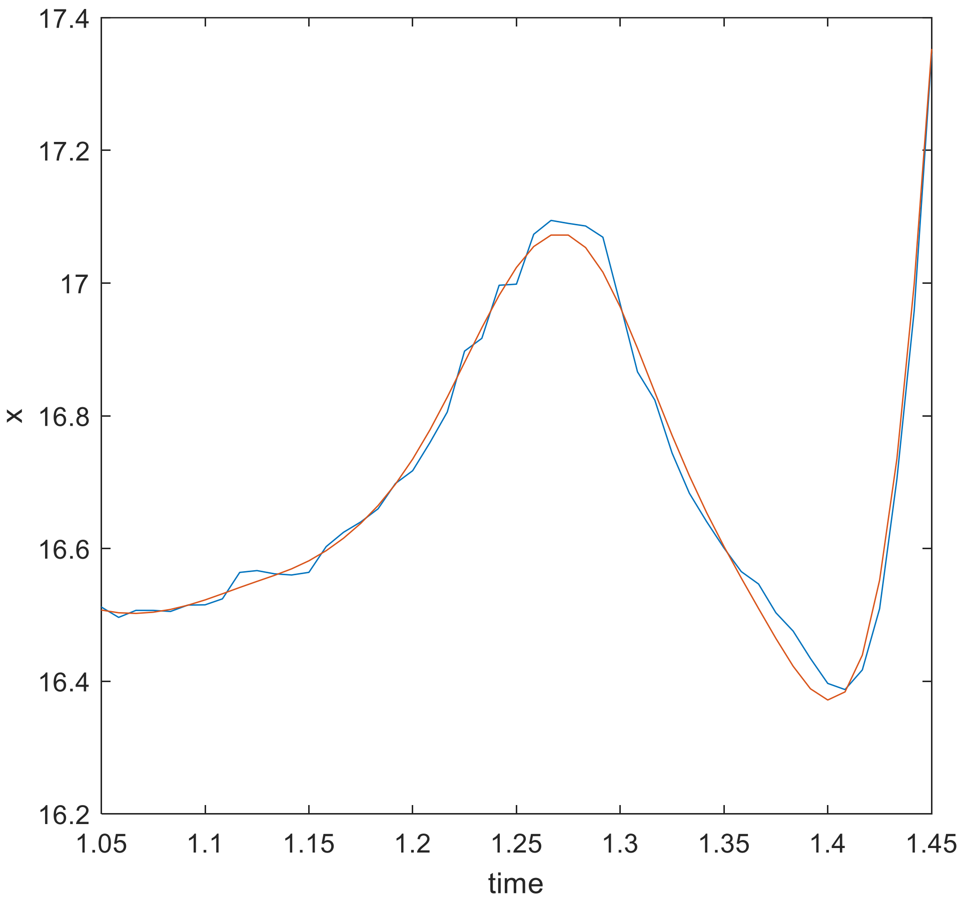


Filtering

Butterworth filter

- One of the most common digital filters for kinematic data
- Basically a sophisticated weighted, recursive, moving average filter
- Order: “width” of surrounding samples
- Cut-off value: which frequencies will pass
- Type of filter: low, high, band-pass

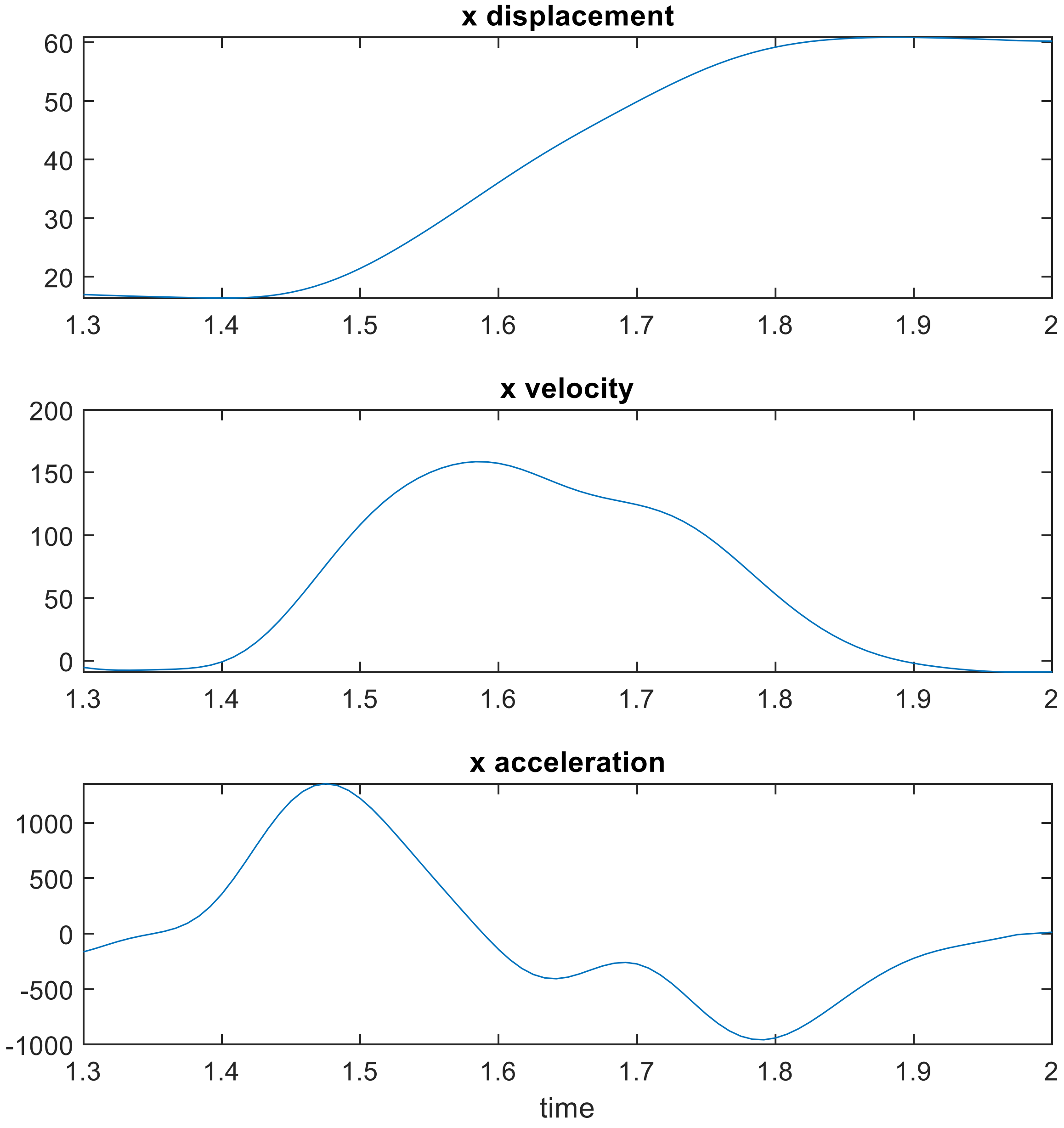
To eliminate phase shift, which is a natural consequence of applying the filter, use it bidirectionally



Velocity and acceleration

From raw displacement data, we can compute

- Velocity ("speed"): 1st derivative
- Acceleration: 2nd derivative
- Jerk: 3rd derivative



What we can see here:

- "bell-shaped" velocity profile
- Velocity extreme values at acceleration zero-crossings

Step 6: Parameter extraction

We can measure or calculate

- Position, rotation
- Velocity, acceleration, jerk (separately for x, y, z or total)
- Number and duration of stops
- Curvature / area under the curve (AUC)
- Distance travelled
- Dwell time, e.g. on a target

Derived measures

- Movement onset and offset
- Movement duration / time
- Max vertical amplitude
- Mean or max (= peak) velocity
- Movement variability
- Number of submovements

Comparing signals

- Autocorrelation, cross-correlation, circularity
- Asynchrony
- Trajectory similarity, e.g. Procrustes analysis

Step 6: Parameter extraction

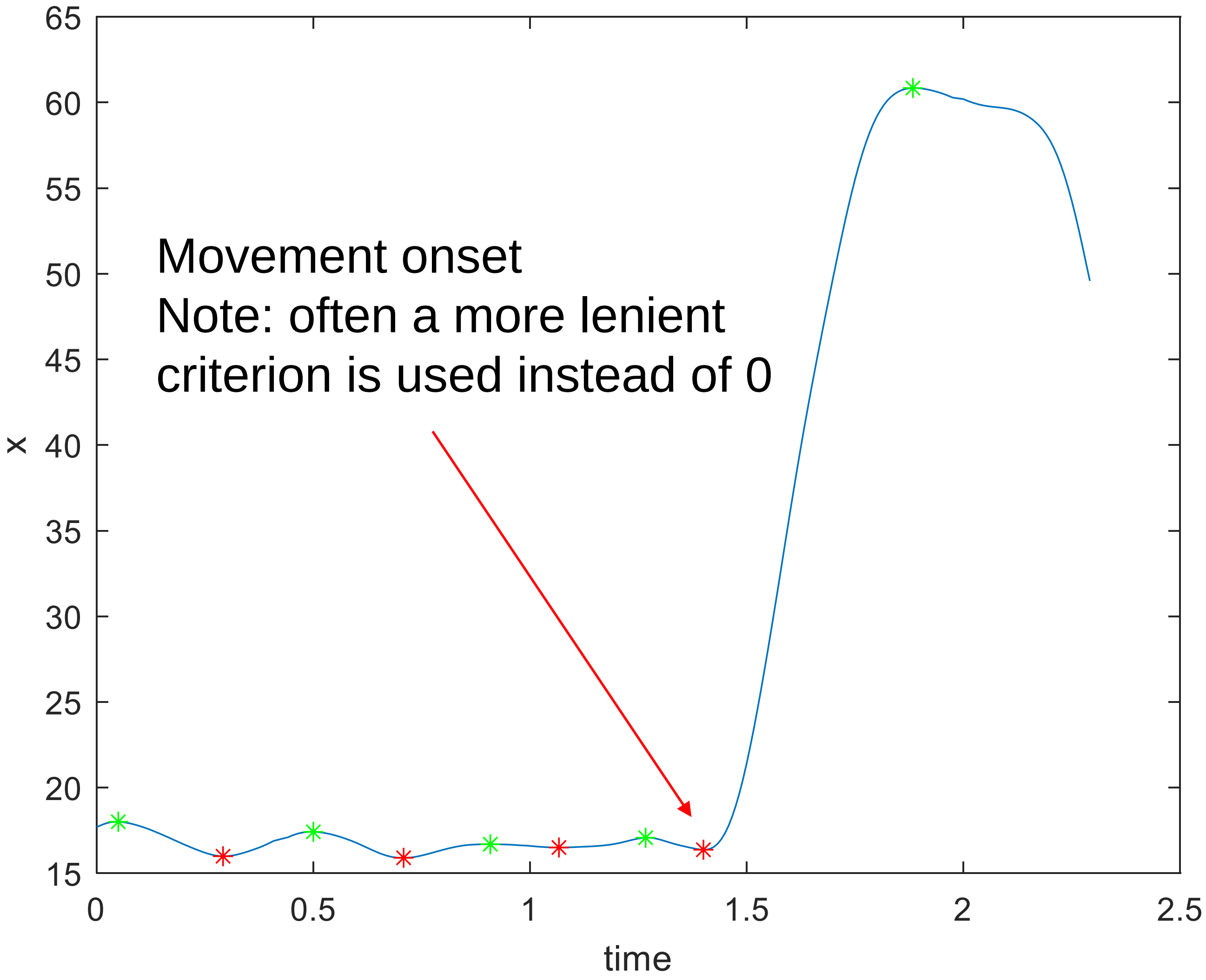
Using zero-crossings in the subsequent derivative, we can determine extreme values in a signal

Movement onset

Using zero-crossings in velocity, we can determine extreme values in position data

Peak velocity

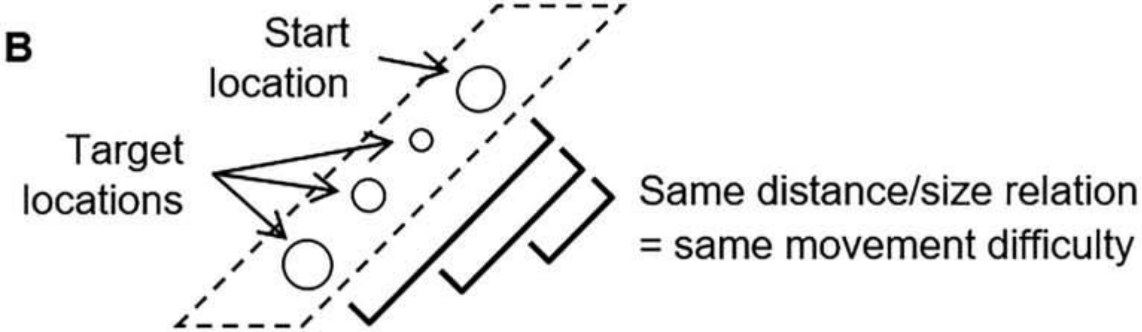
Using zero-crossings in acceleration, we can determine extreme values in velocity

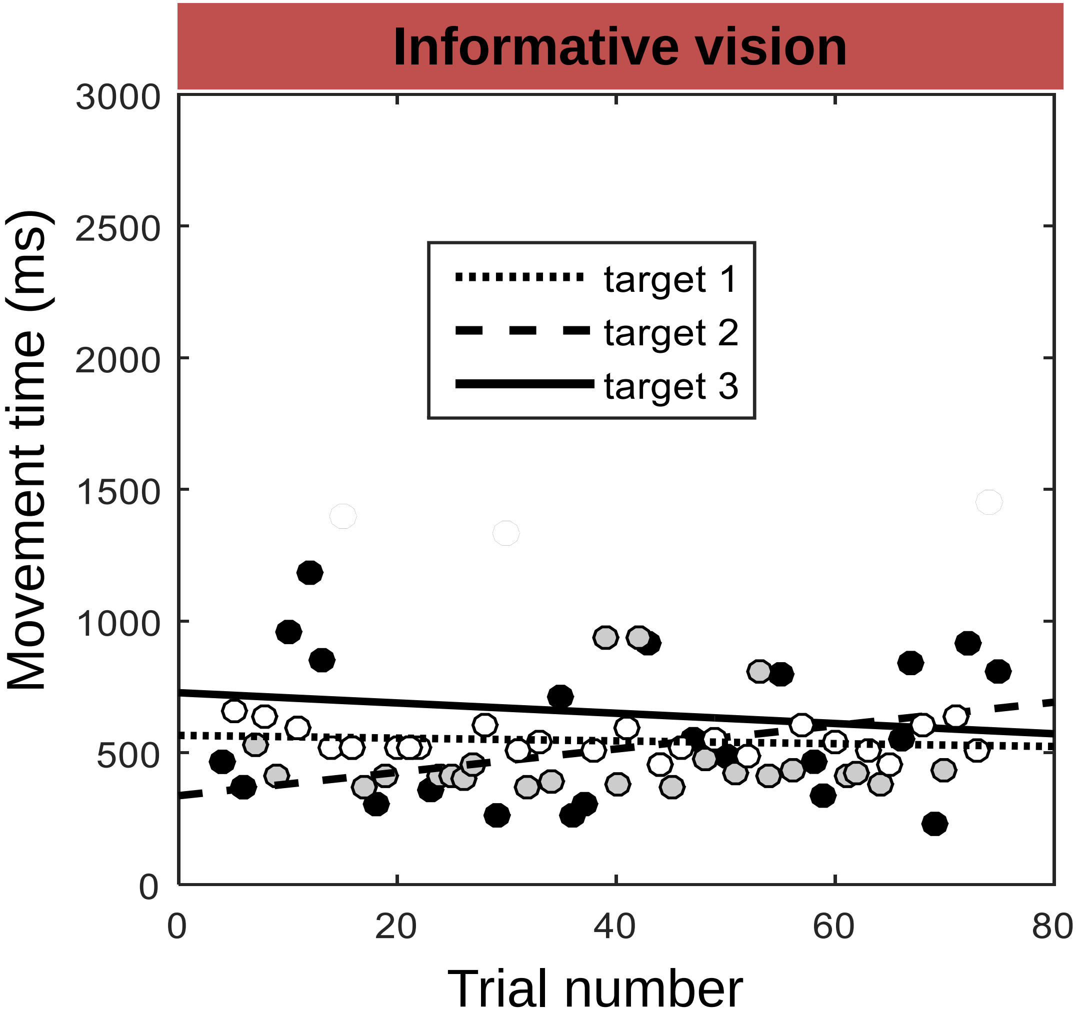


Step 7: Interpreting kinematic parameters wrt to research question

Do people deviate from efficient performance?

1) Does Fitts' law hold in baseline?
2) Is Fitts' law violated in 'Uninformative'?





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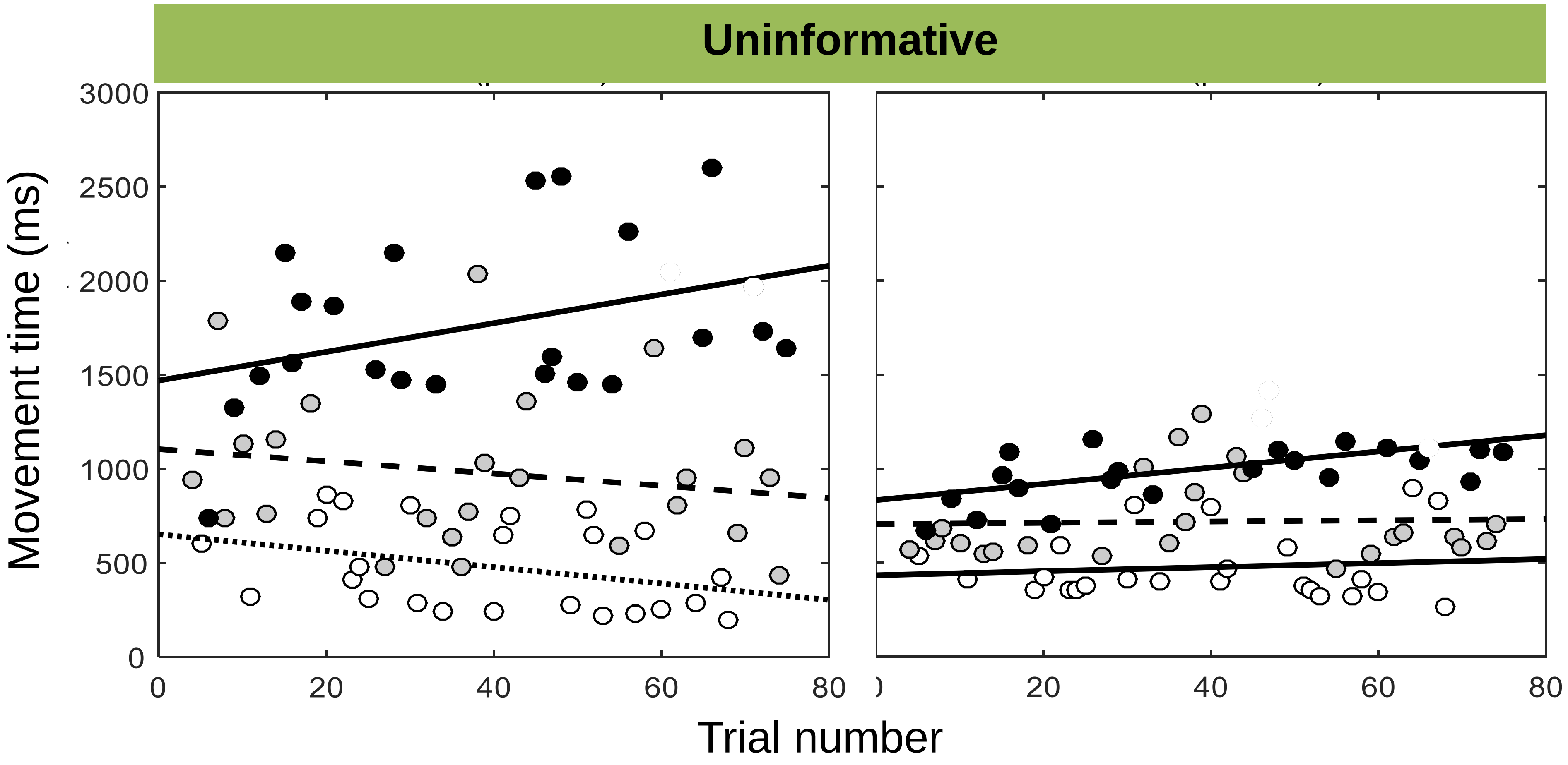
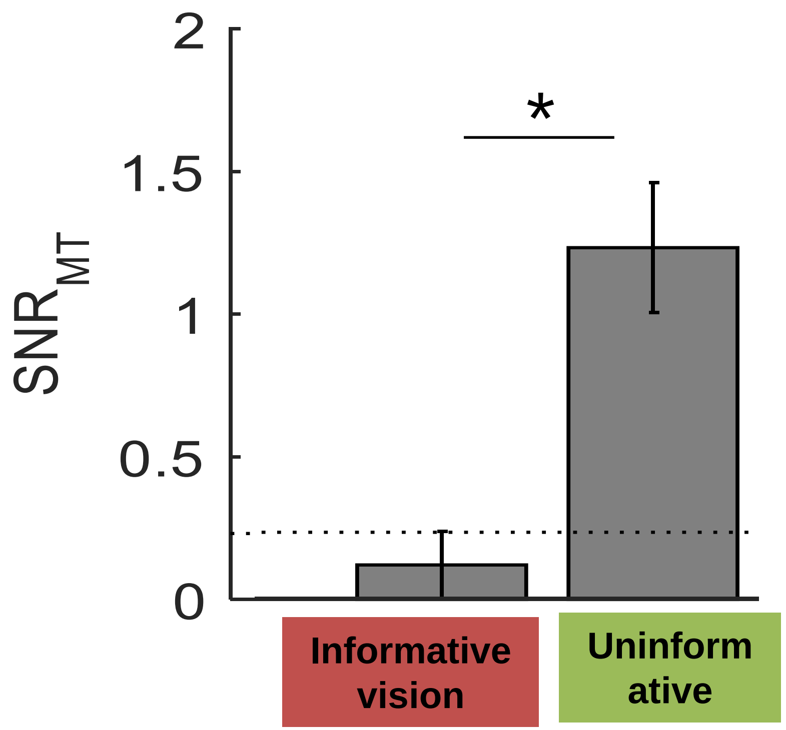


Step 7: Interpreting kinematic parameters wrt to research question

$$\text{Signal-to-noise ratio} = \frac{\text{Duration difference}}{\text{Variability of duration}}$$

$$SNR = \frac{M((M_{target\ 2} - M_{target\ 1}),\ (M_{target\ 3} - M_{target\ 2}))}{M\ \ (SD_{target\ 1},\ SD_{target\ 2},\ SD_{target\ 3})}$$

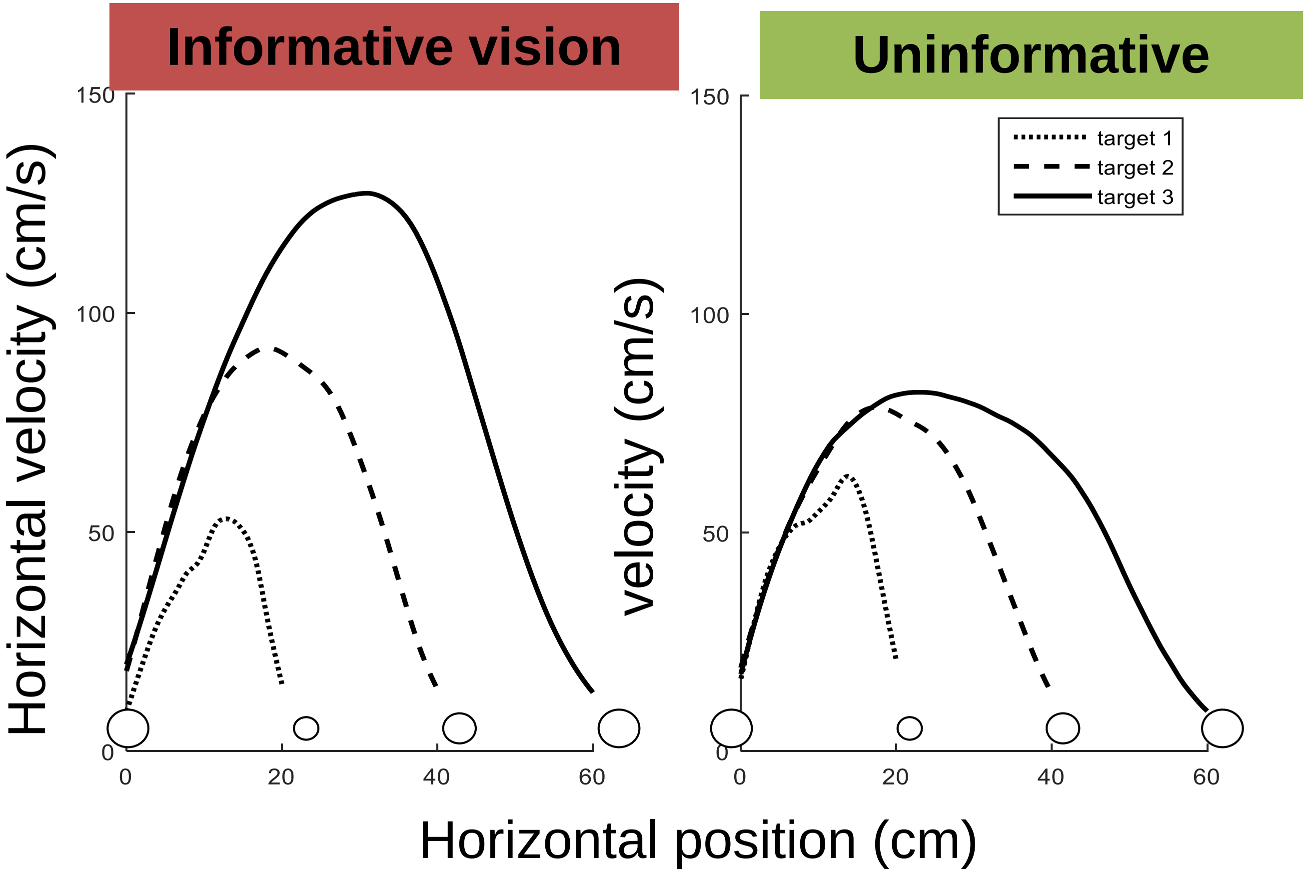


Step 7: Interpreting kinematic parameters wrt to research question

Differences in velocity profiles: More uniform velocity for the three different targets in ‘Uninformative’

Conclusion

- Active modulation of basic kinematic parameters to communicate to a task partner
- Differentiating targets by ‘inefficient’ action performance
- Consistent with **sensorimotor communication** literature



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Step 3: Deciding on measurement technique(s)

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Step 5: <u>Data preprocessing</u>

Inspection and corrections

Filtering

Velocity and acceleration

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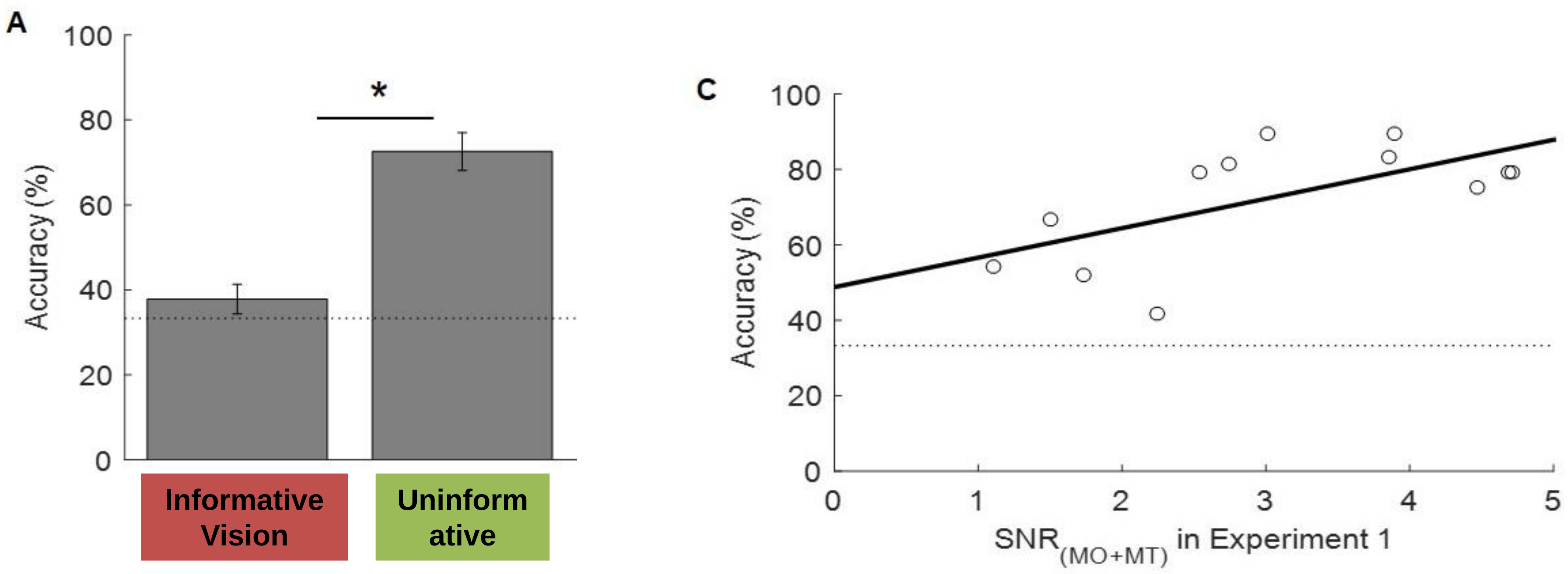
<u>Example for today</u>: Vesper, C., Schmitz, L., & Knoblich, G. (2017). Modulating action duration to establish non-conventional communication. *Journal of Experimental Psychology: General*, *164*(12), 1722–1737.

Creating new means of communication

Can others understand the newly developed communication system?

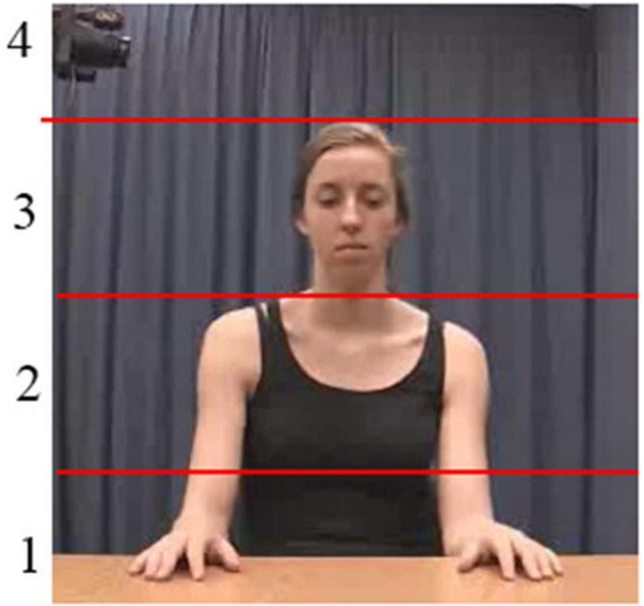


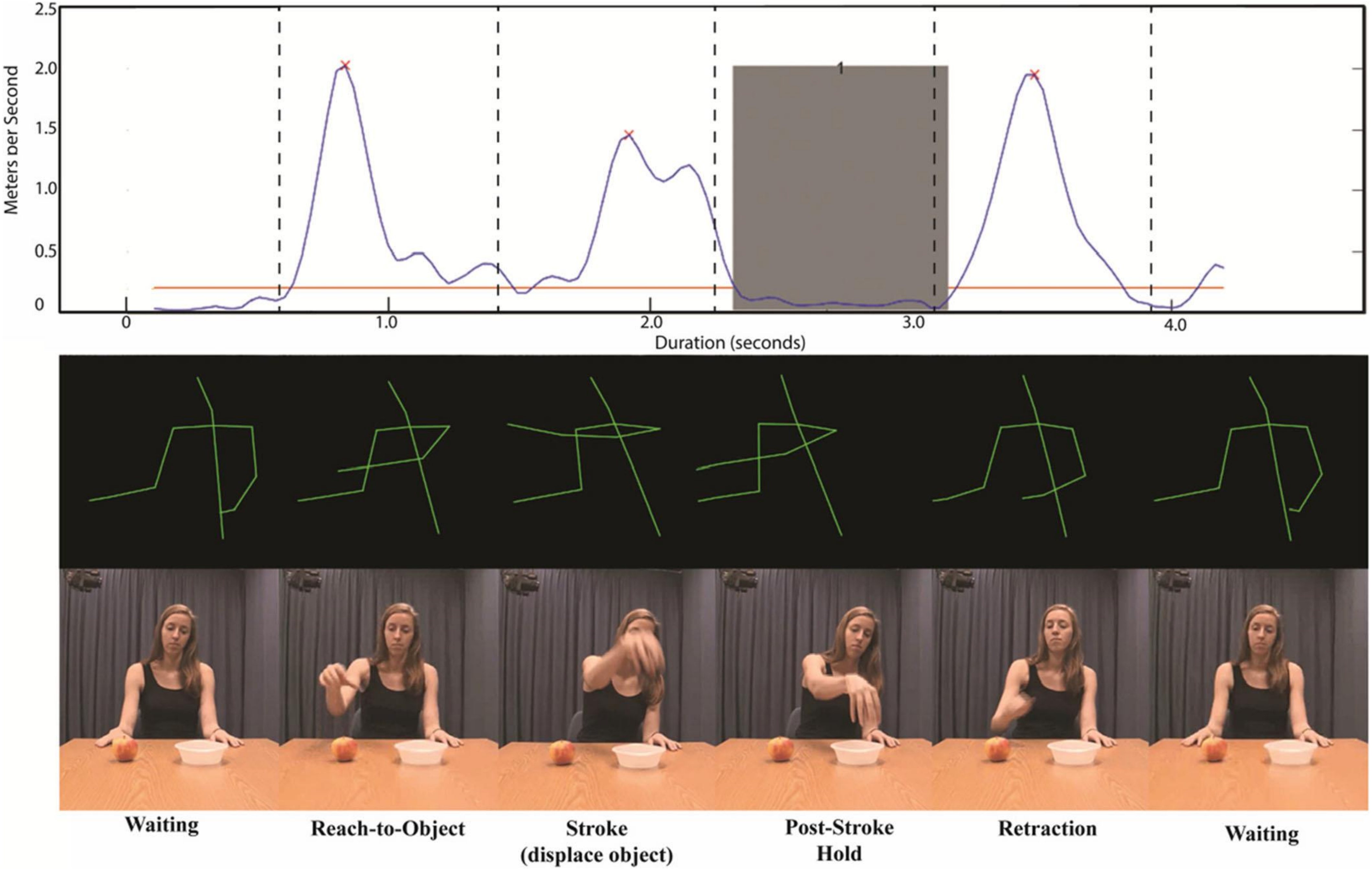
Further examples: Gestures

Nice tutorial Trujillo et al., 2018

Uses Microsoft Kinect data to quantify kinematic features of gestures:

- Vertical amplitude
- Peak velocity
- Submovements
- Hold counts

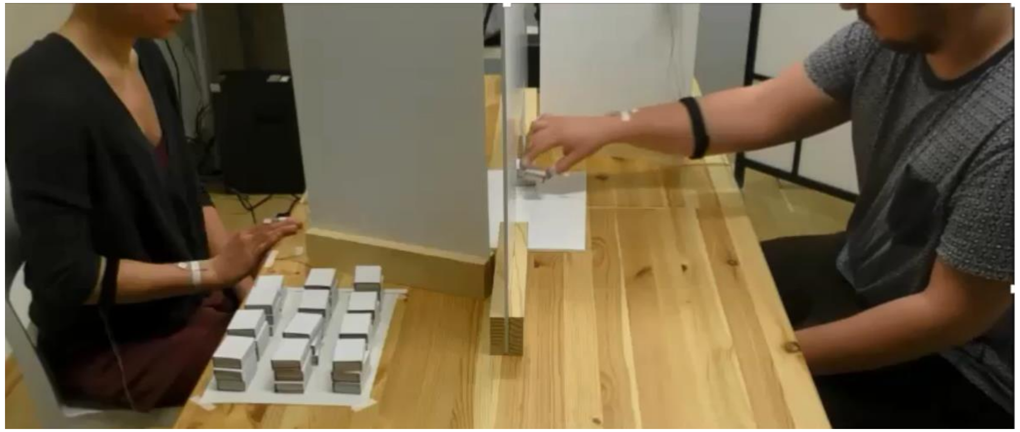


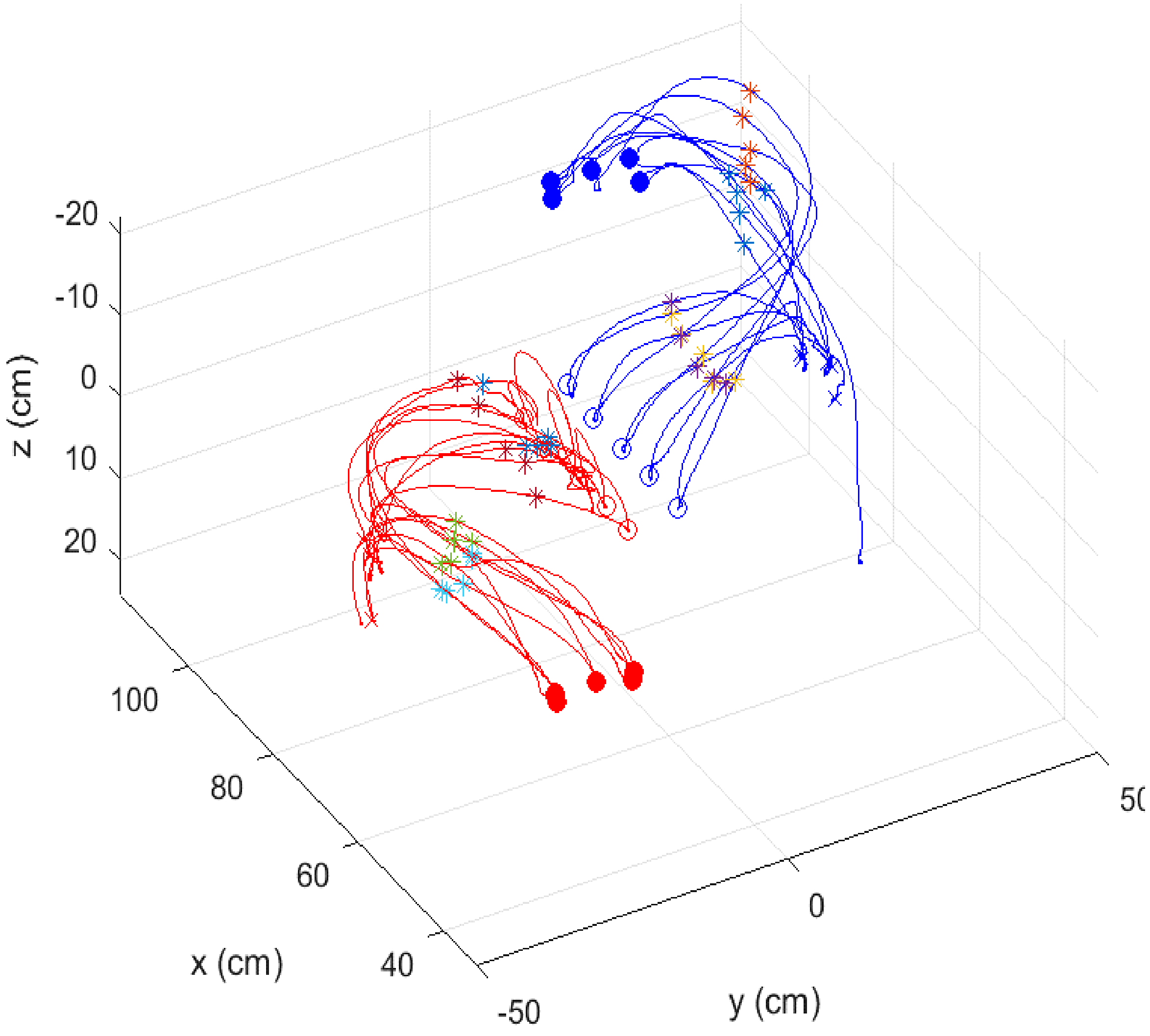

Meters per Second
2.5
2.0
1.5
1.0
0.5
0
1
0
1.0
2.0
3.0
4.0
Duration (seconds)
Waiting
Reach-to-Object
Stroke
(displace object)
Post-Stroke
Hold
Retraction
Waiting

Further examples: Gestures

Do people use gesture complexity as a way to differentiate objects in a joint matching task? Vesper et al., in preparation

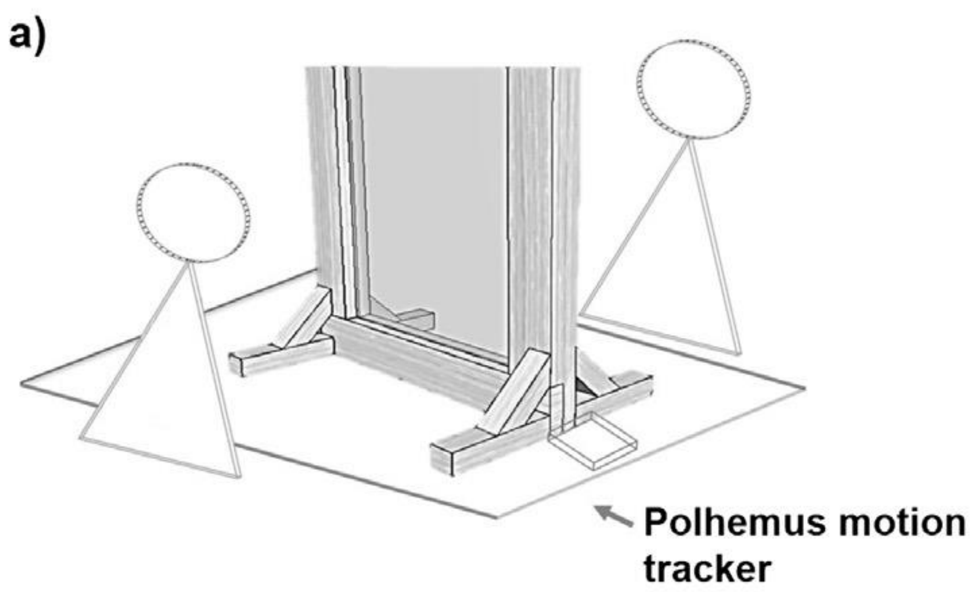
- Movement time
- Submovements

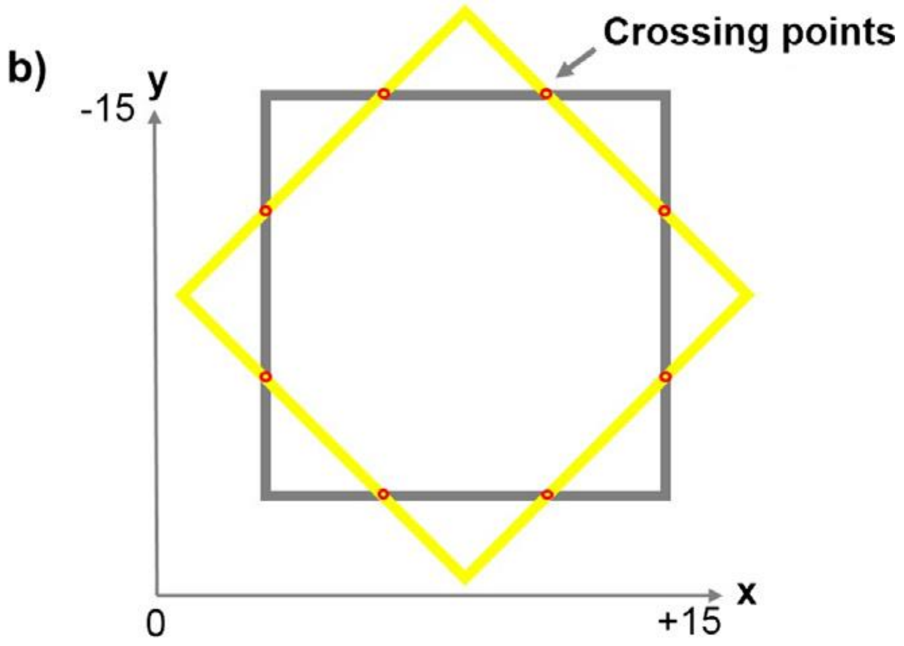




Further examples: Social adjustment of velocity profiles

Do co-actors overcome own constraints to adjust to each other’s movements?





Curioni et al., 2019

Further examples: Social adjustment of velocity profiles

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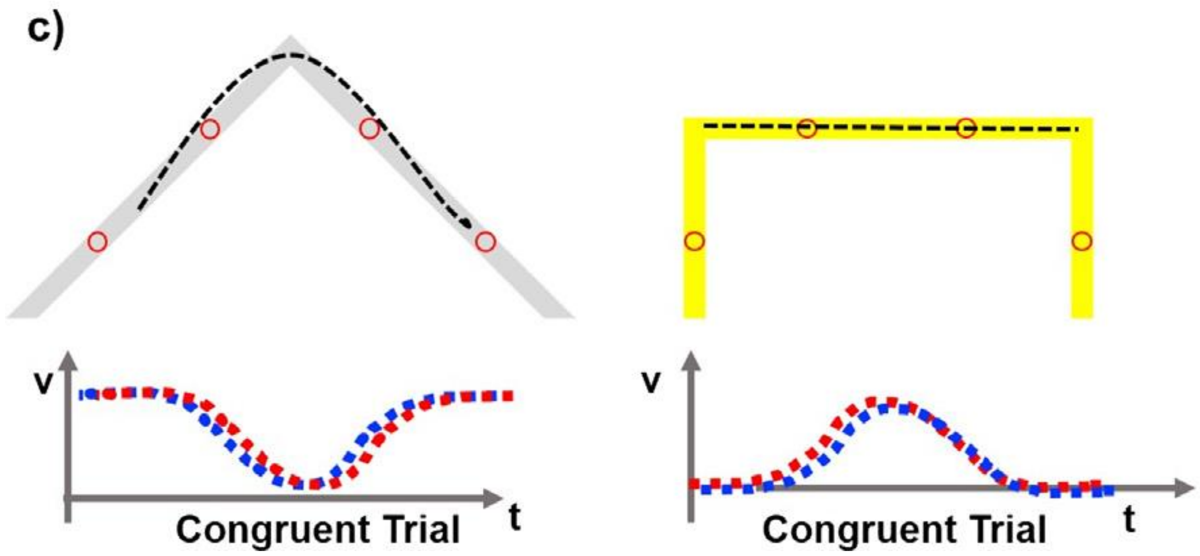
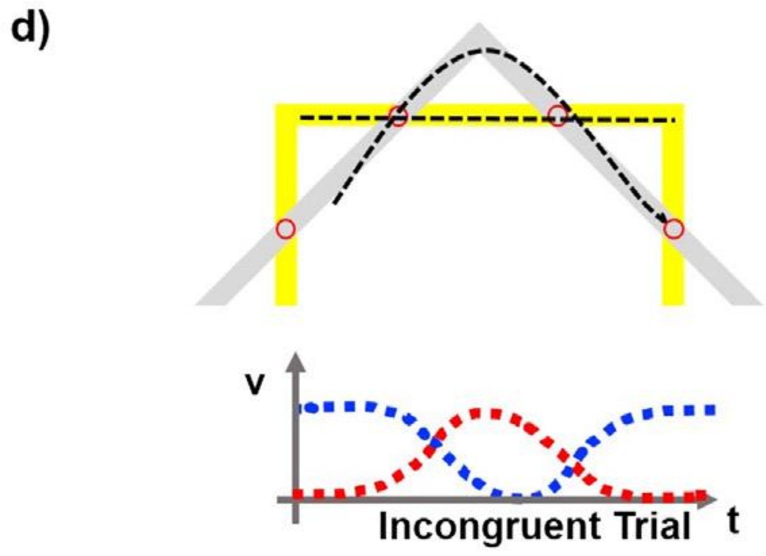
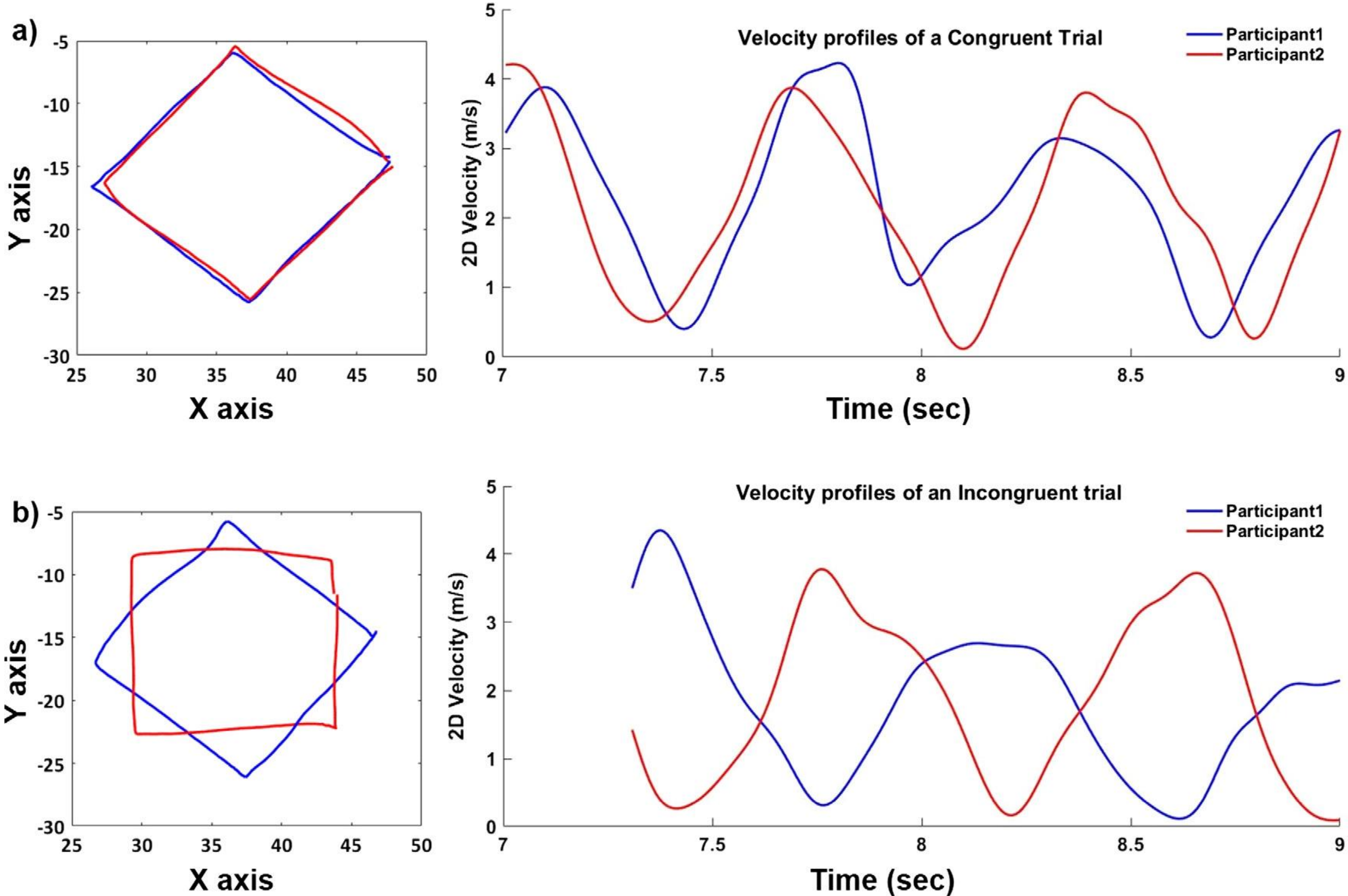




Curioni et al., 2019


a)
Y axis
X axis
Velocity profiles of a Congruent Trial
Participant1
Participant2
2D Velocity (m/s)
Time (sec)
b)
Y axis
X axis
Velocity profiles of an Incongruent trial
Participant1
Participant2
2D Velocity (m/s)
Time (sec)

Further examples: Social adjustment of velocity profiles

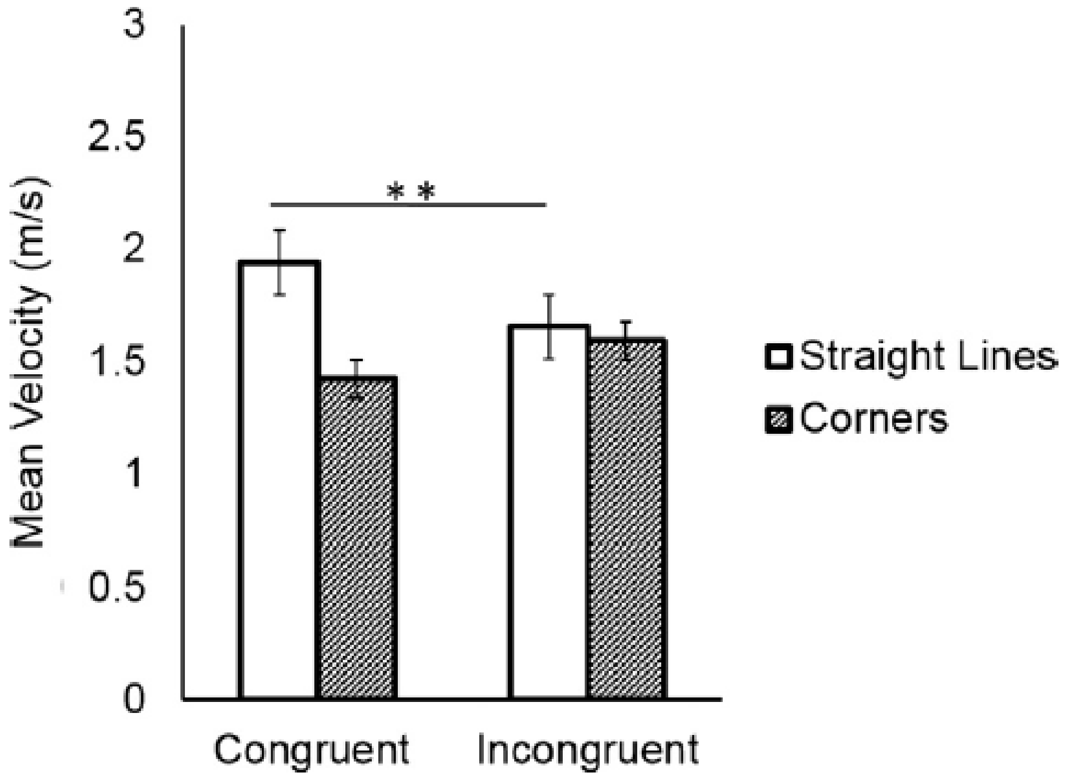


Fig. 3. In the congruent condition, participants moved faster along straight-line segments than around corners. In the incongruent condition, they adjusted to their partner, slowing down on straight-line segments. Asterisks indicate the significance level of Tukey post hoc tests (*: $p < 0.05$, **: $p < 0.01$).

Curioni et al., 2019

Take-home messages

- Motion tracking is a powerful technique that allows temporally and spatially precise analysis of (human) action performance
- Tracking systems differ greatly: from optical to magnetic sensing, depending on the type and number of sensors, range, sensitivity to occlusions and noise, pricing etc.
- Data preprocessing usually takes a big part of the work: inspection and corrections, filtering, calculating derived measures
- Rather little standardization in the field and no unified tools

Main references

Vesper, C., Schmitz, L., & Knoblich, G. (2017). Modulating action duration to establish non-conventional communication. *Journal of Experimental Psychology: General*, *164*(12), 1722–1737.

Fitts, P. M. (1954). The information capacity of the human motor system in controlling the amplitude of movement. *Journal of Experimental Psychology*, *47*(6), 381–391.

Trujillo, J. P., Vaitonyte, J., Simanova, I., & Özyürek, A. (2018). Toward the markerless and automatic analysis of kinematic features: A toolkit for gesture and movement research. *Behavior Research Methods*.

Pezzulo, G., Donnarumma, F., & Dindo, H. (2013). Human Sensorimotor Communication: A Theory of Signaling in Online Social Interactions. *PLOS ONE*, *8*(11), e79876–e79876.

Curioni, A., Vesper, C., Knoblich, G., & Sebanz, N. (2019). Reciprocal information flow and role distribution support joint action coordination. *Cognition*, *187*, 21–31.