“Elementary behaviors” (or movement primitives) in voluntary movement

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work done by

- Britta Grimme
- John Lipinski
- Eva Nowak
- Hendrik Reimann

three types of invariance in movement

- task/behavioral variables
- scaling, isochrony
- elementary behaviors

task/behavioral variables

- movements are prepared/planned and perceptually registered in terms of the trajectory of an end-effector in space
  - hand in space
  - foot in space
  - direction of body in space

task/behavioral variables

- evidence
  - regularity and invariance of end-effector paths under changes of biomechanical conditions
    - e.g.,. under loading, under force-field adaptation, etc.
  - uncontrolled manifold
  - population code in motor and pre-motor cortex, Georgopoulos et al…

isochrony

- movement trajectories can be rescaled spatially, maintaining the same absolute or relative timing
- evidence
  - e.g., making small vs. large hand-writing, same percent time spent making each part of the letter
  - performing the same path with different movement time
  - => “simple” templates of movement that can be parametrically adjusted in movement time…
  - => rather than e.g., torque profiles or acceleration profiles…

elementary behaviors

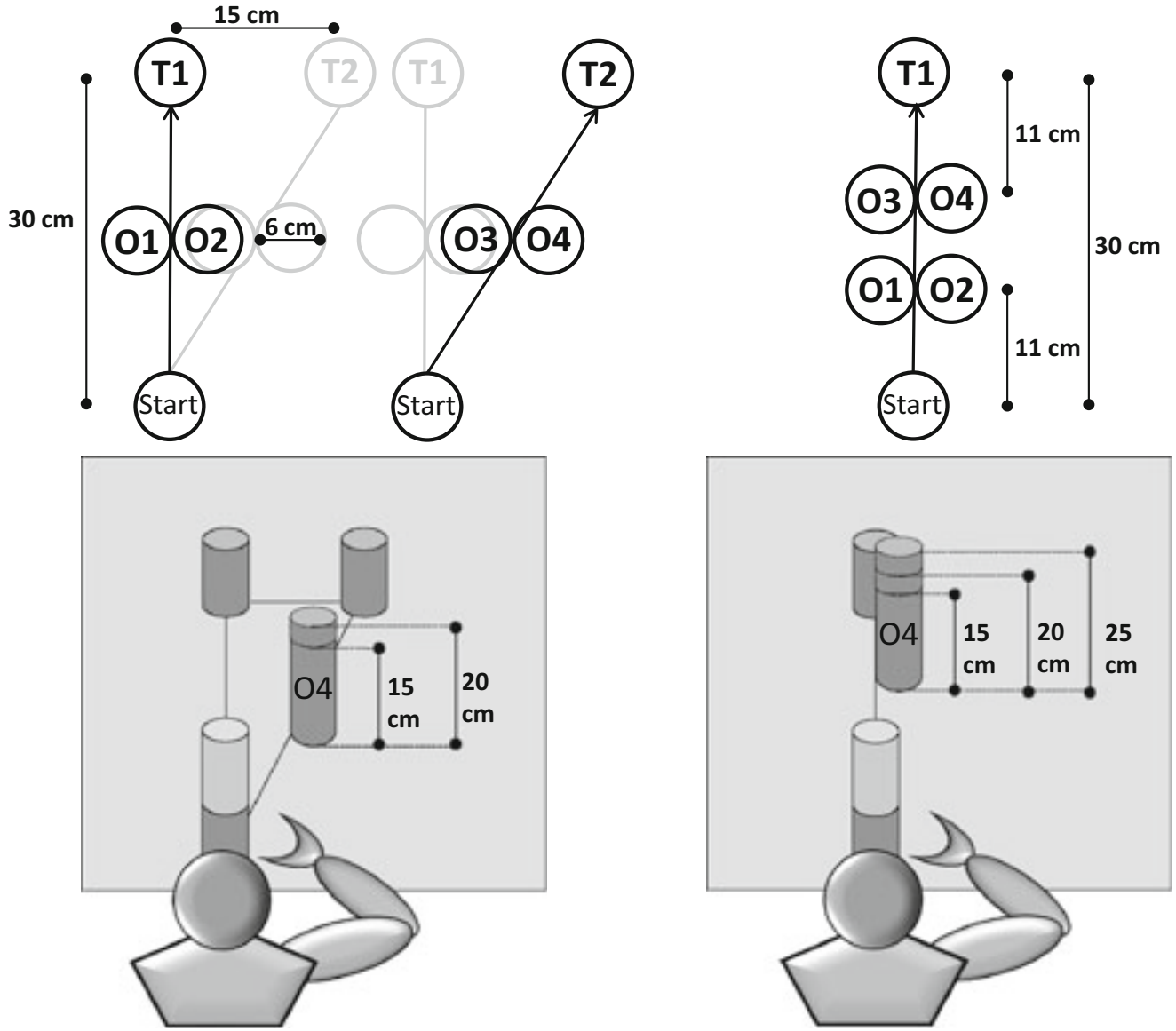
- complex movements can be understood as resulting from the superposition of simple, elementary behaviors…
  - which are generated by behavioral dynamics
  - e.g. movement toward target in the presence of an obstacle is the result of superposing a dynamics of target acquisition on top of a dynamics of obstacle avoidance
- and as a result, task parameters go into particular elementary behaviors, leaving others invariant

elementary behaviors

- evidence:
  - Warren et al…
  - Grimme…

Experiment

- naturalistic movements: hand moving objects to targets while avoiding obstacles, arm unconstrained 10 DoF….
- complex when the spatial arrangement of obstacles is varied…
- may that apparent complexity emerge from simple invariant elementary movements?



[Grimme, Lipinski, Schöner, EBR 2011]

paths

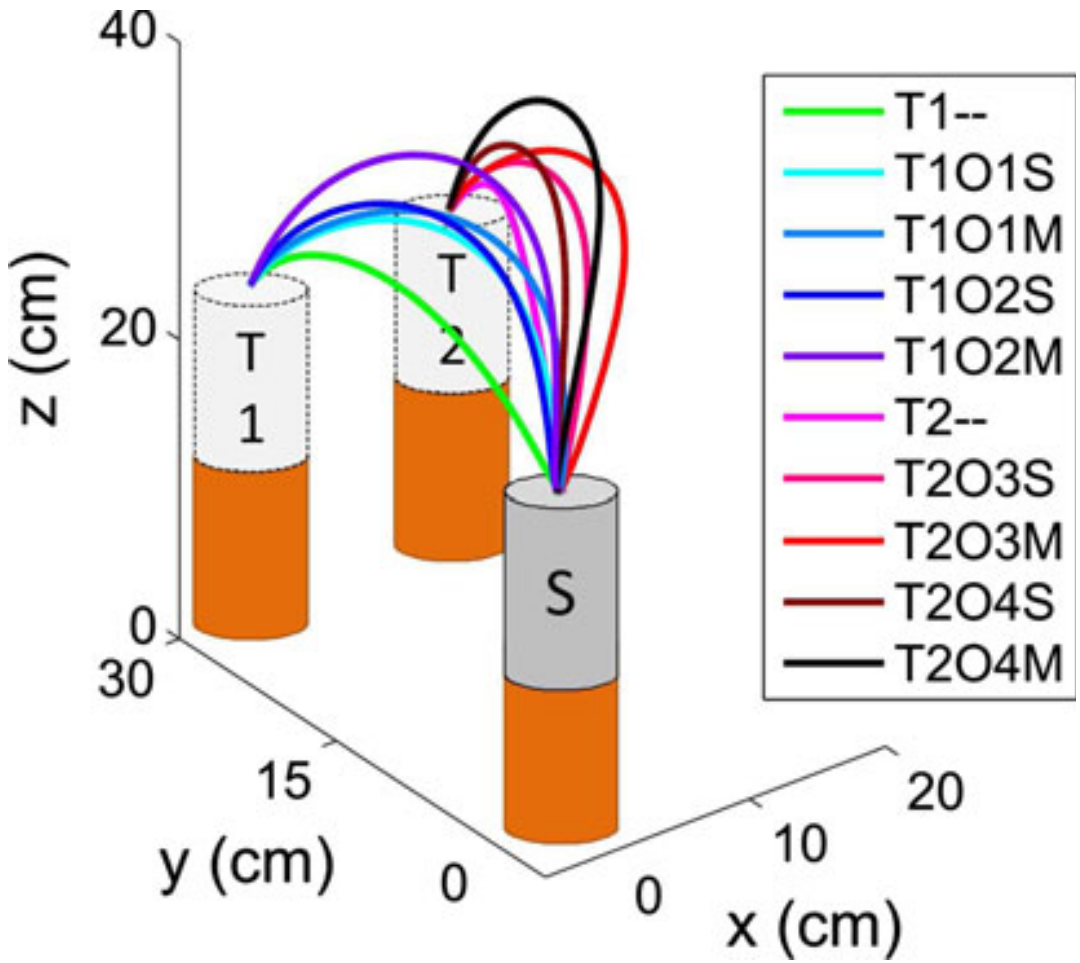
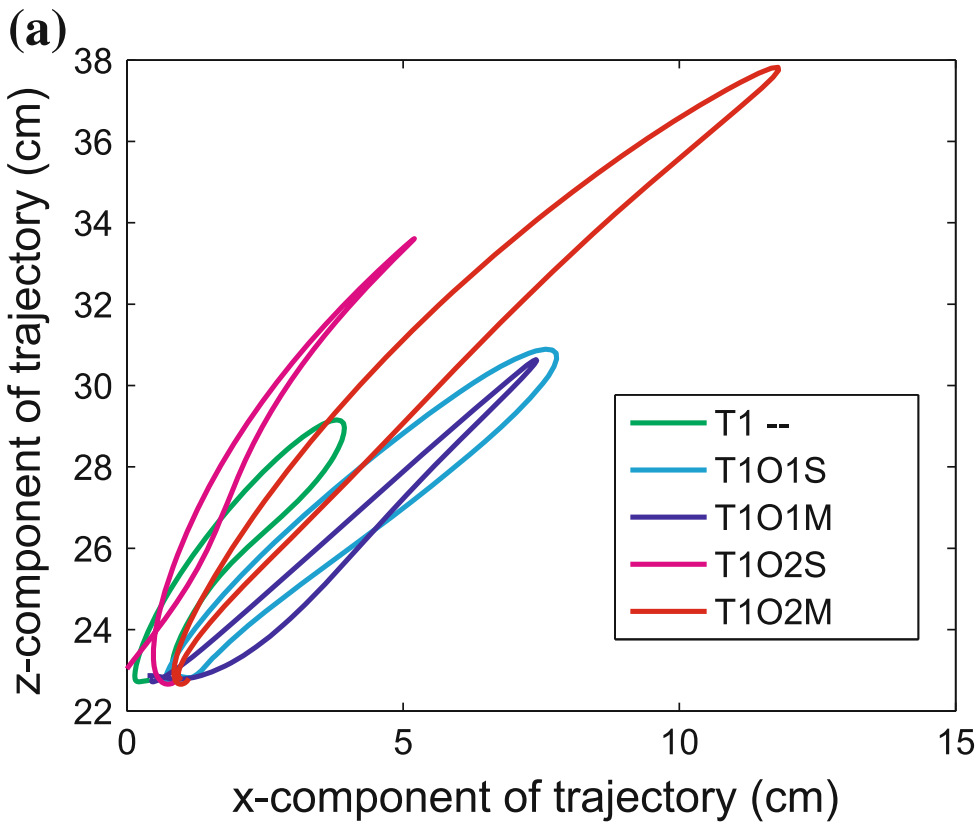
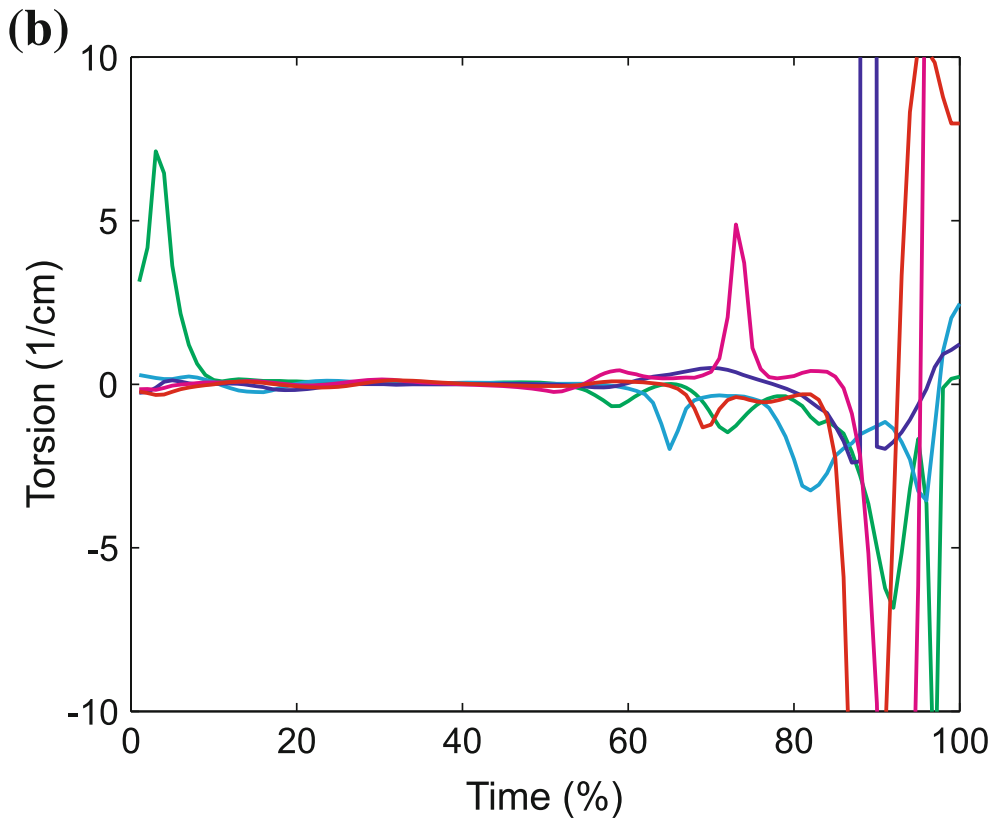


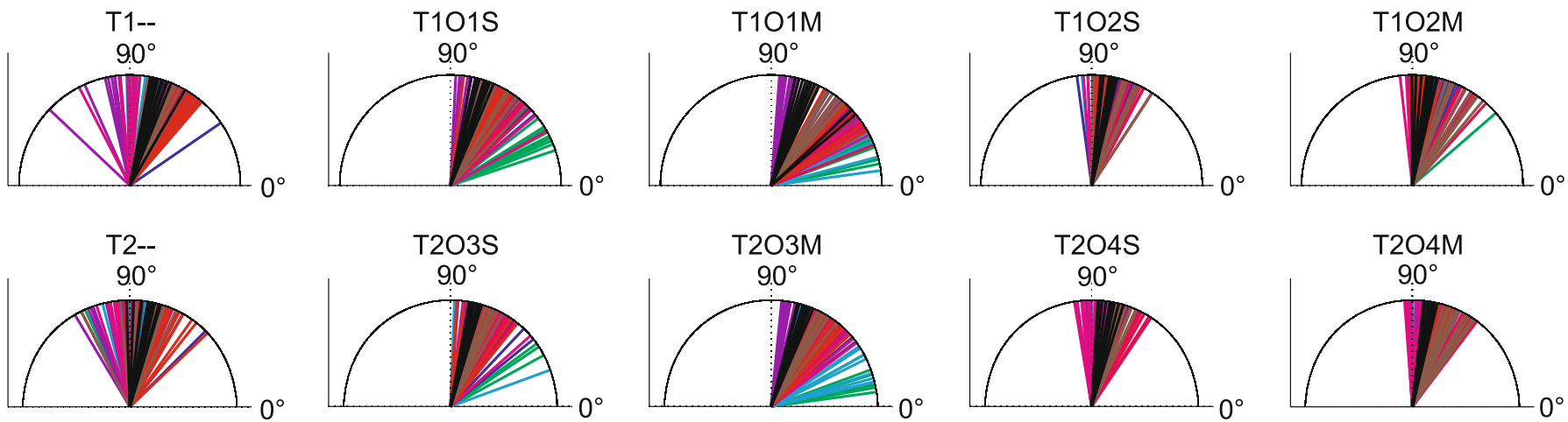
Fig. 3 Mean (over all participants) 3D obstacle avoidance paths from the starting position (*S*) to both target positions (*T1* and *T2*)

paths are planar



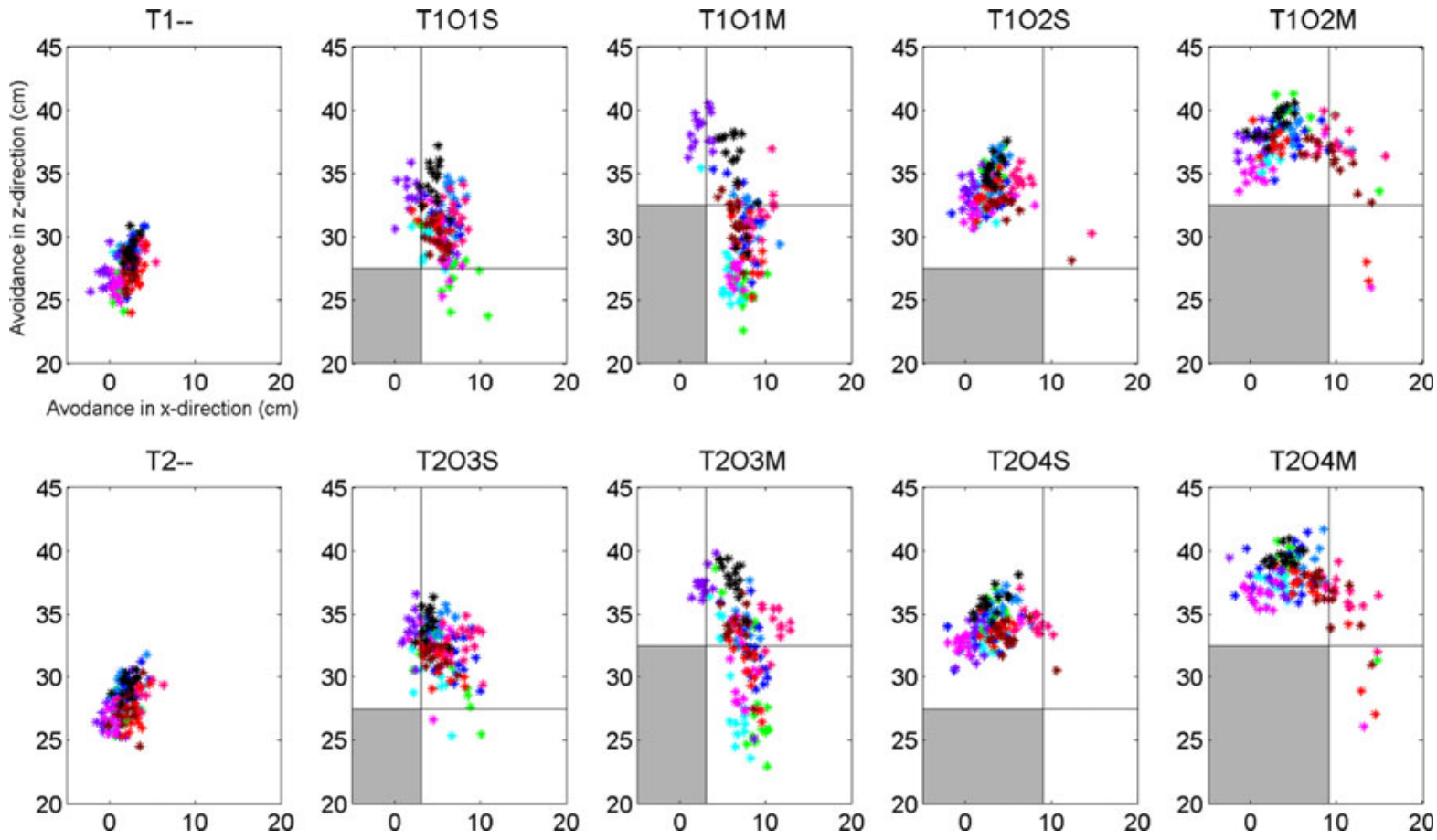


the plane of movement depends on the obstacle height



colors: participants…

the plane of movement depends on the obstacle height

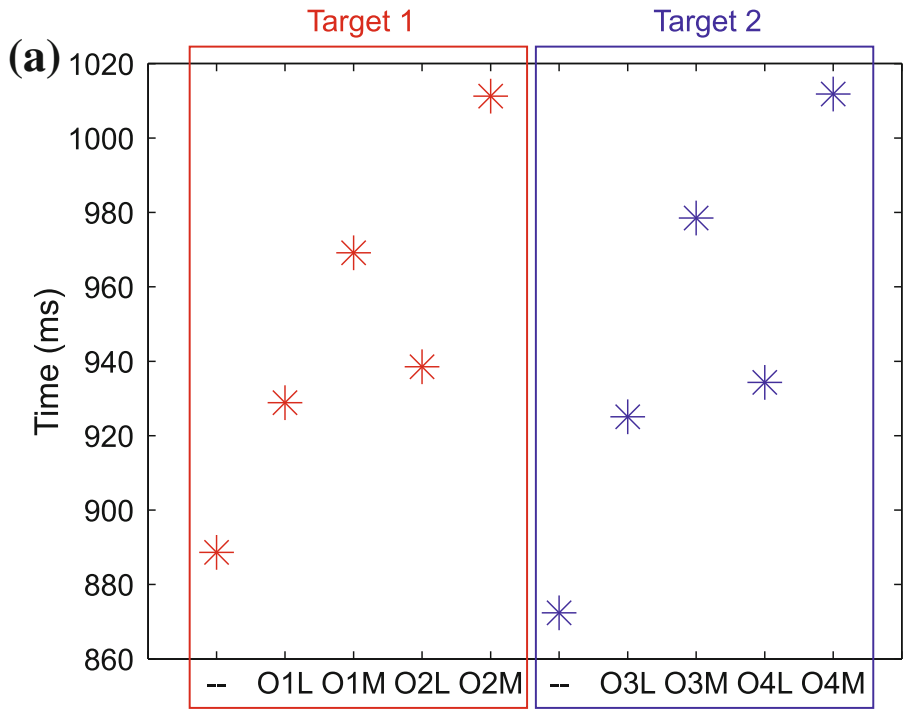


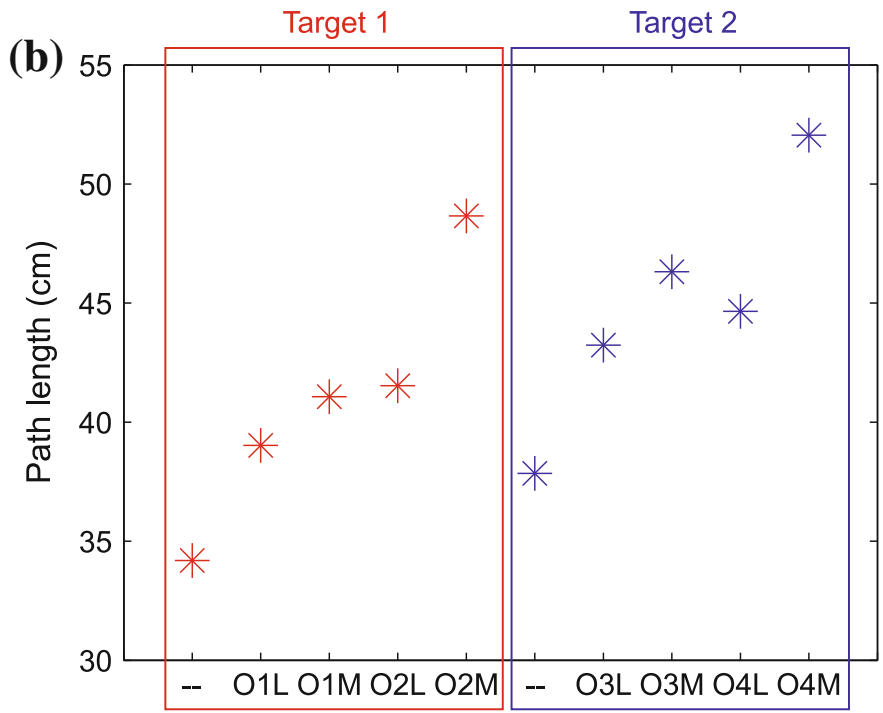
colors: participants…

=> end-effector path

- is simple and invariant…

isochrony

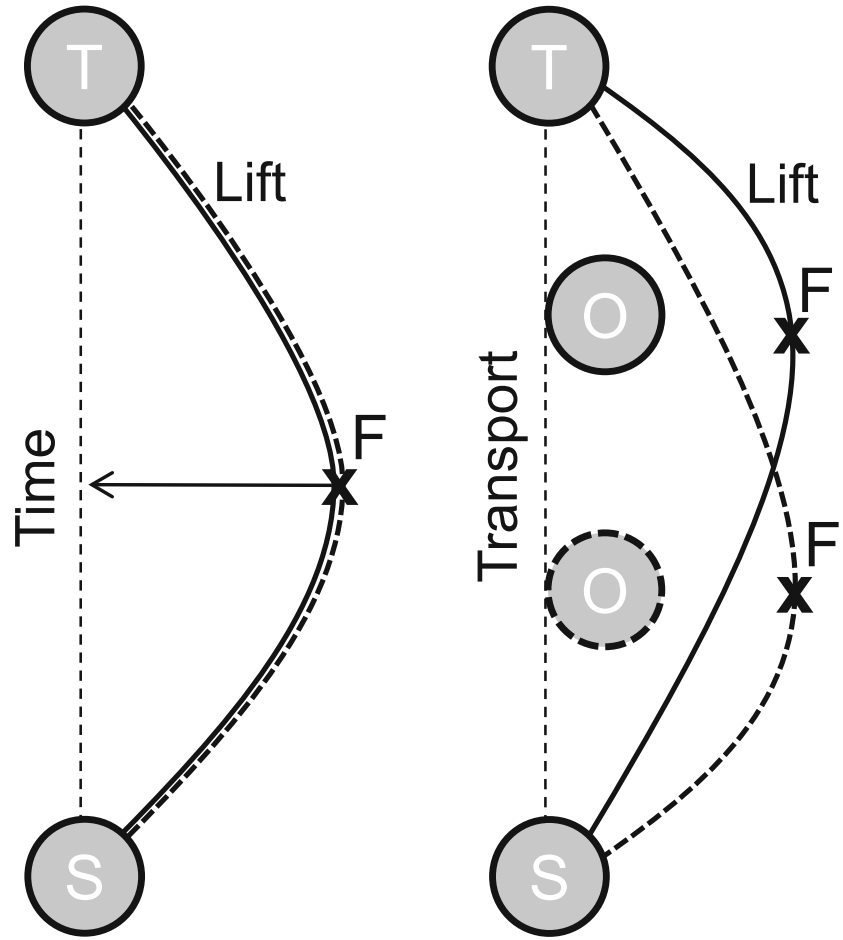




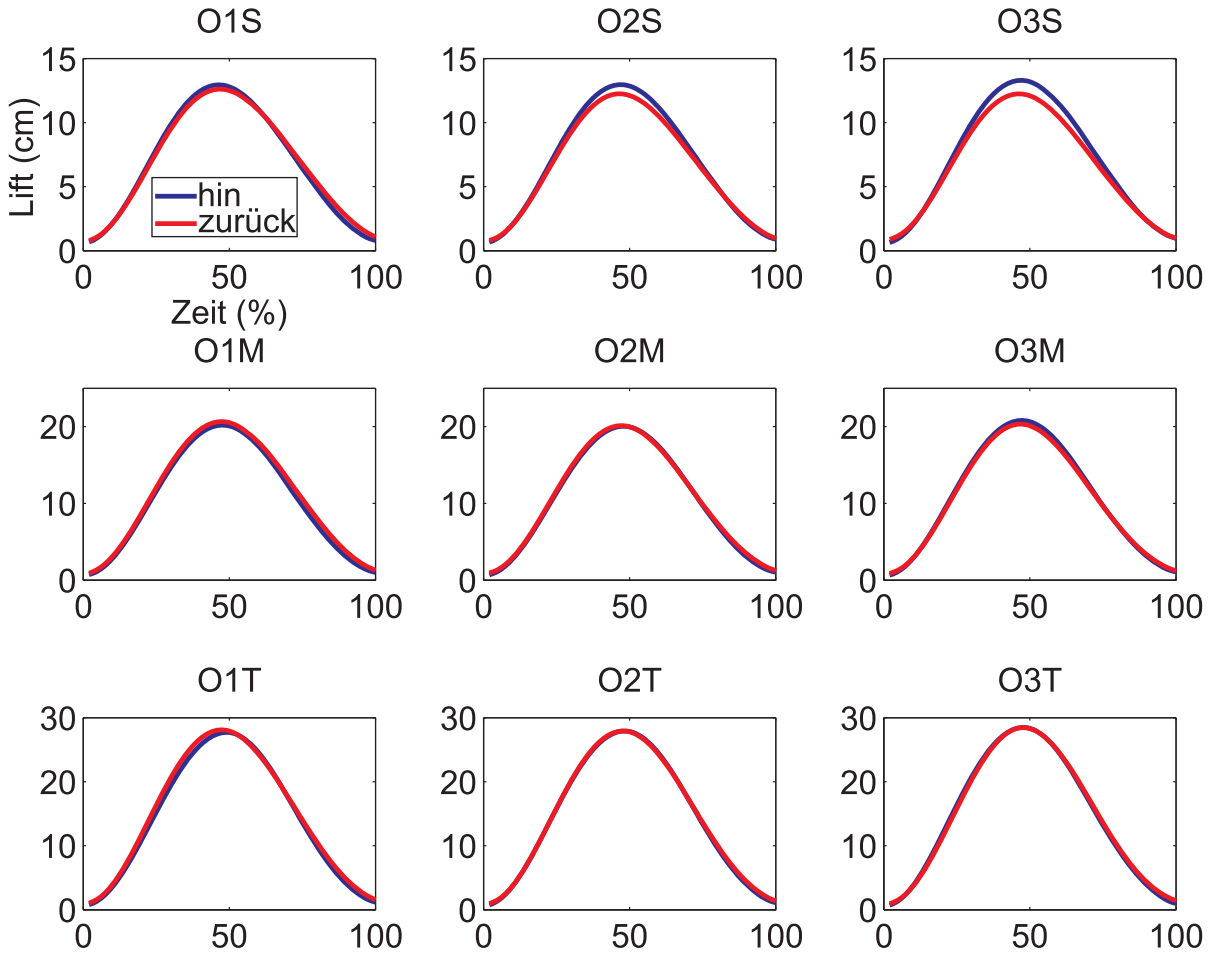
same movement time

different path length

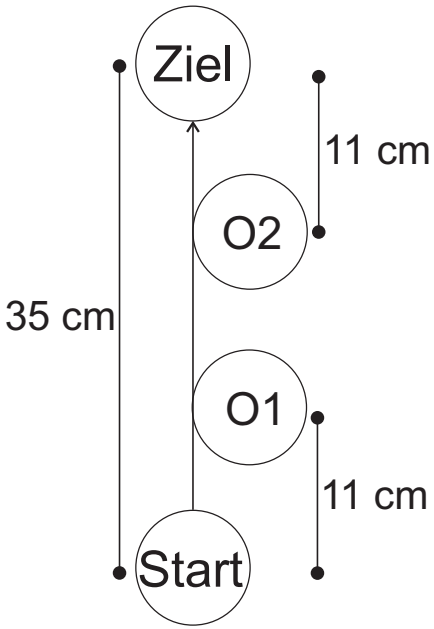
local isochrony

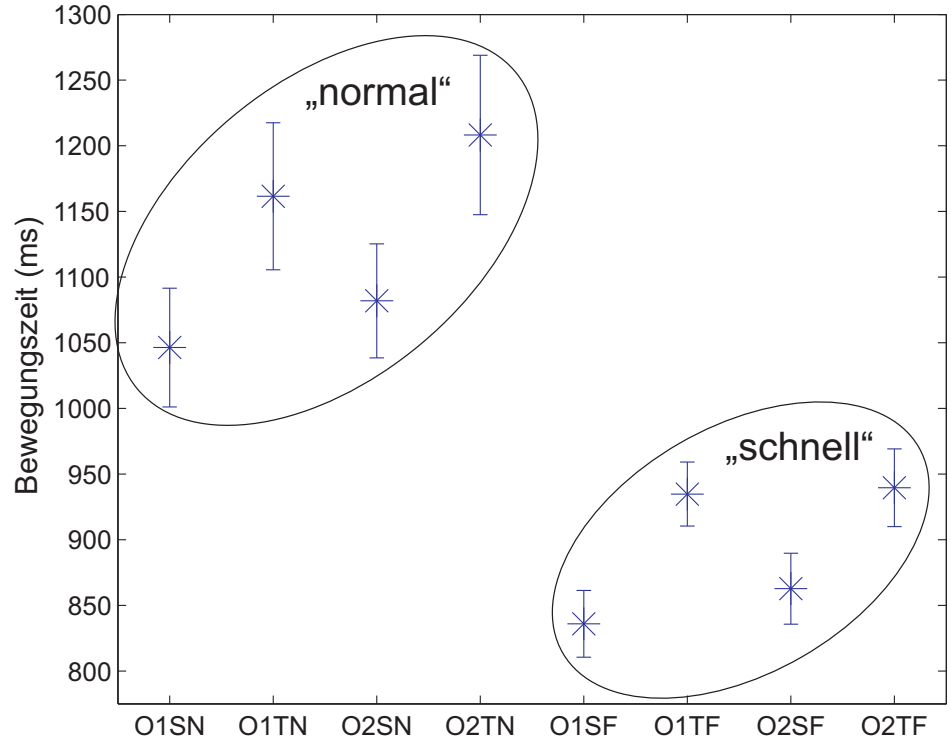


invariance of lift across space

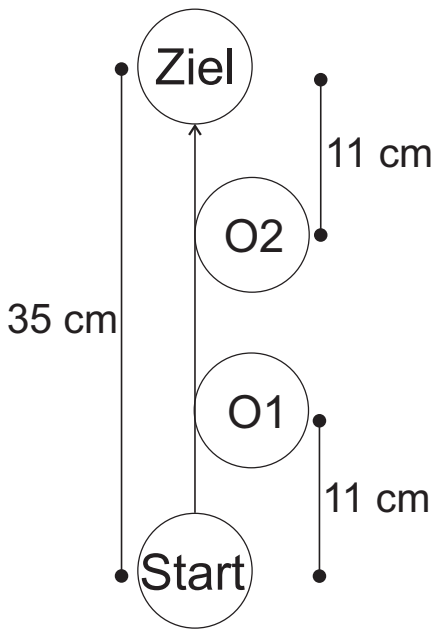


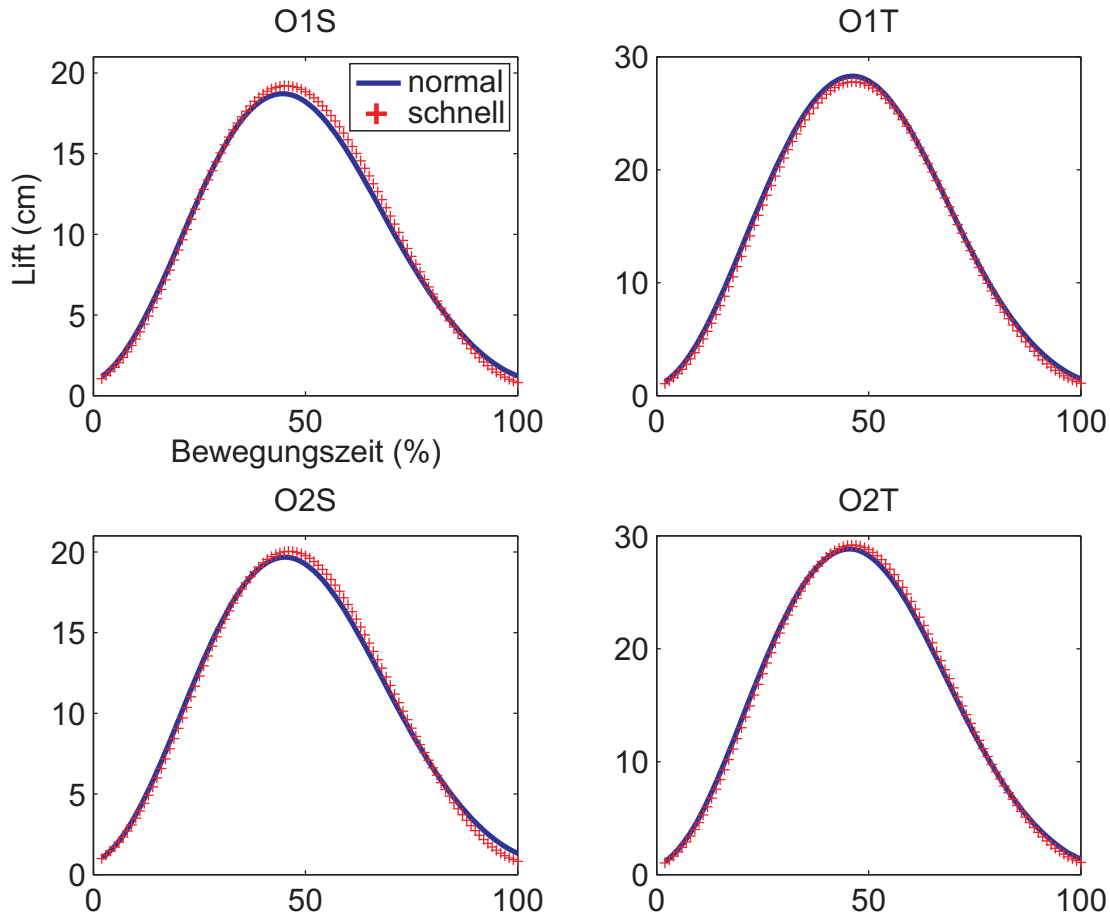
scaling with movement time



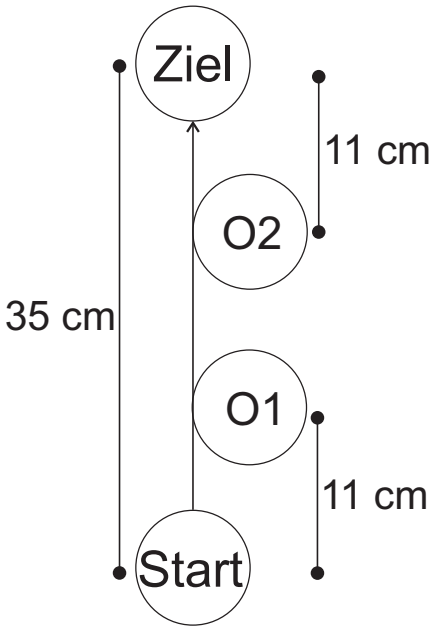


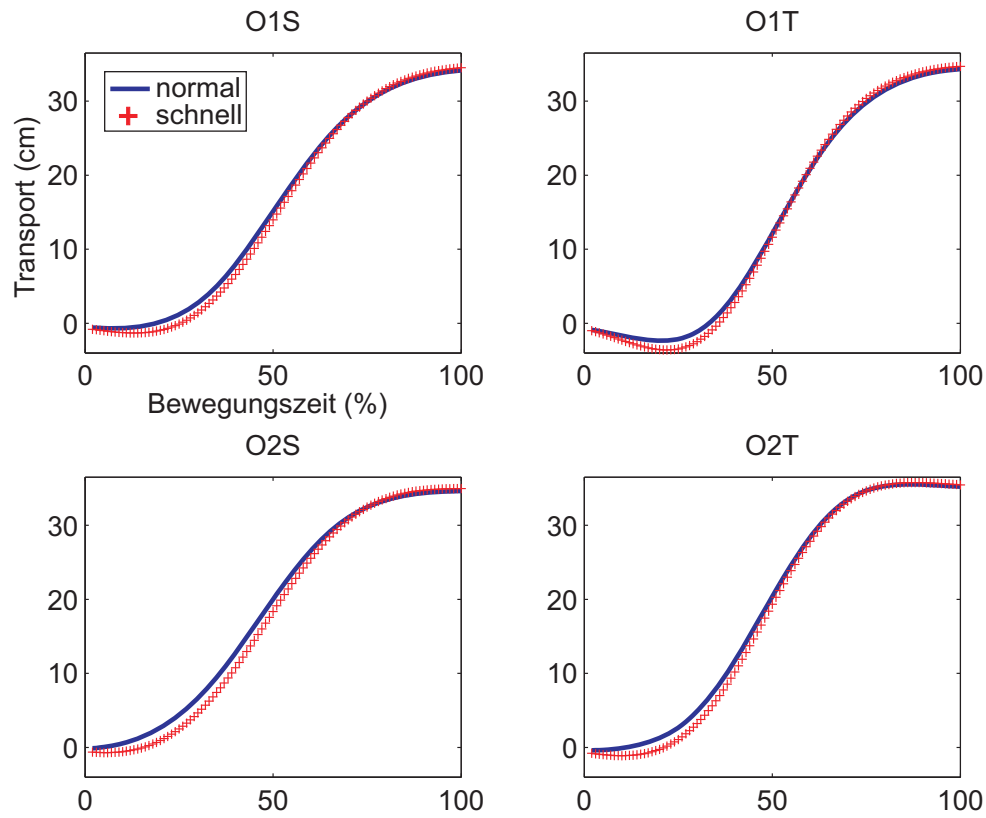
scaling with movement time





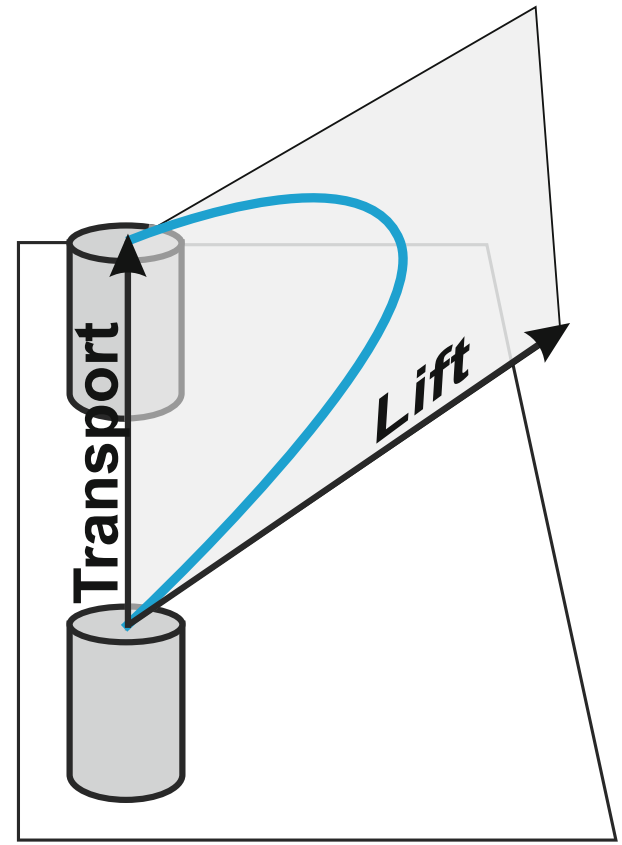
scaling with movement time



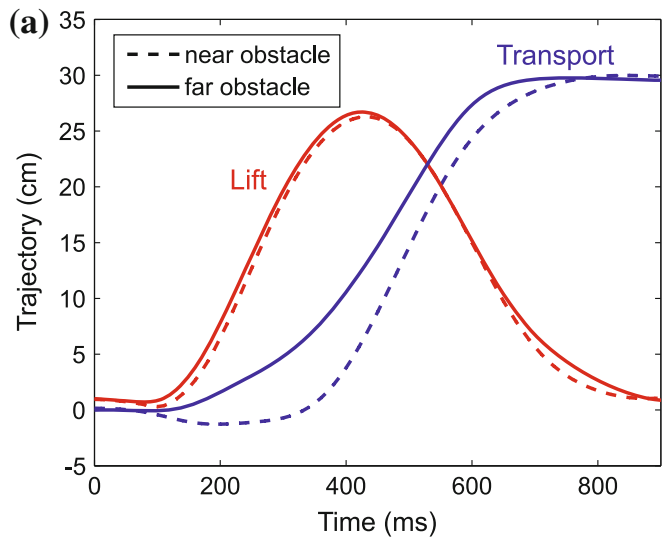


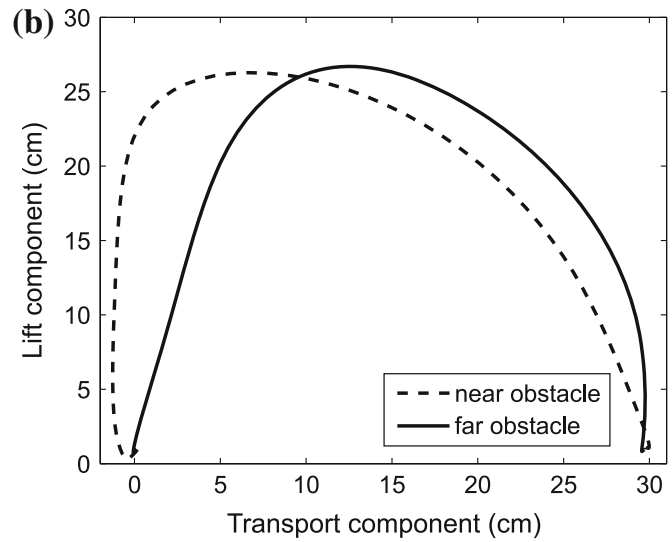
elementary behaviors

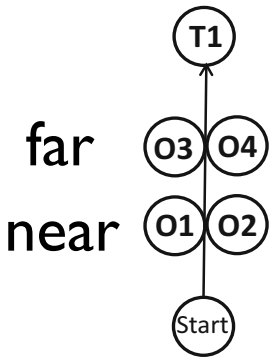
- based on planarity
- decompose movement into transport and lift component

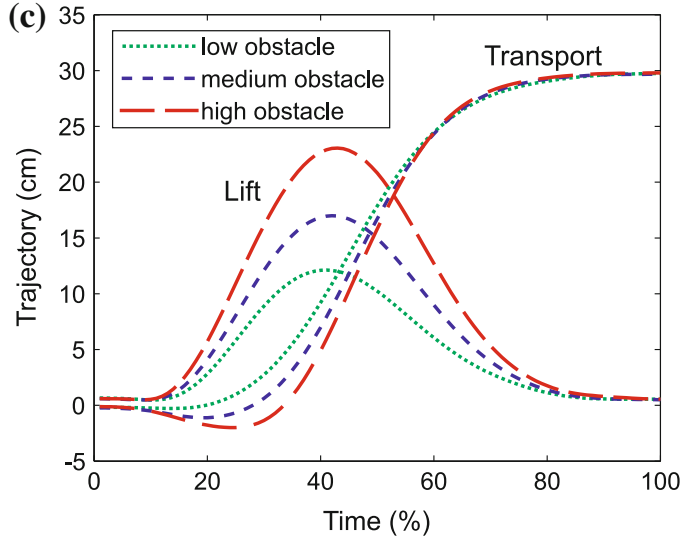


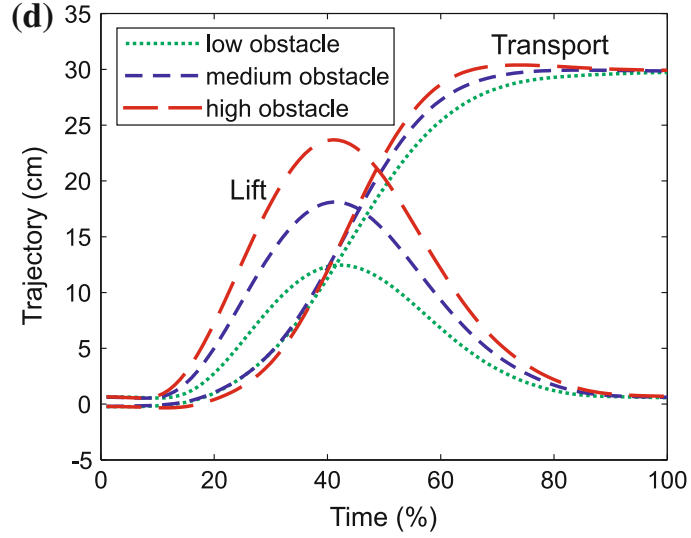
lift vs. transport







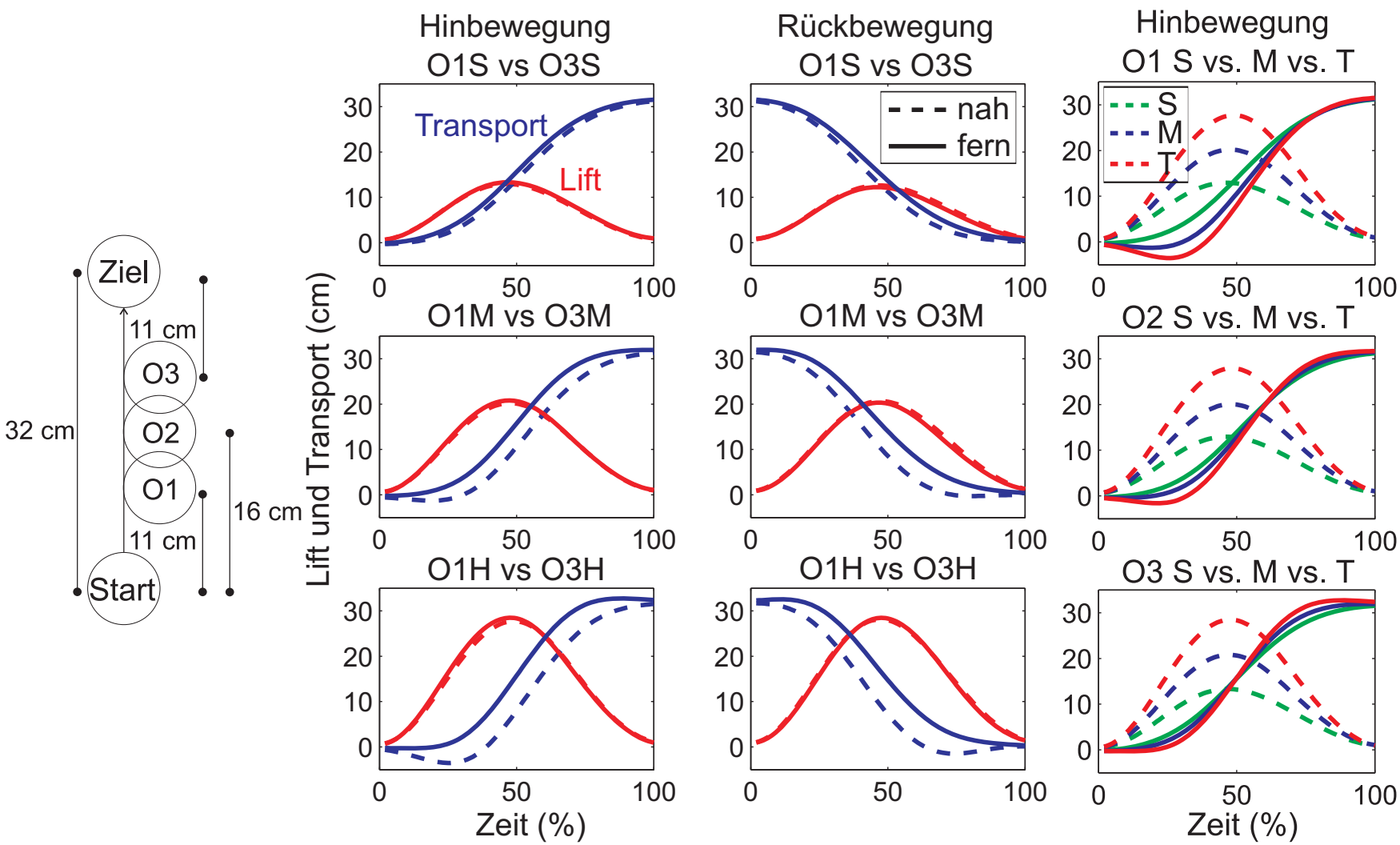




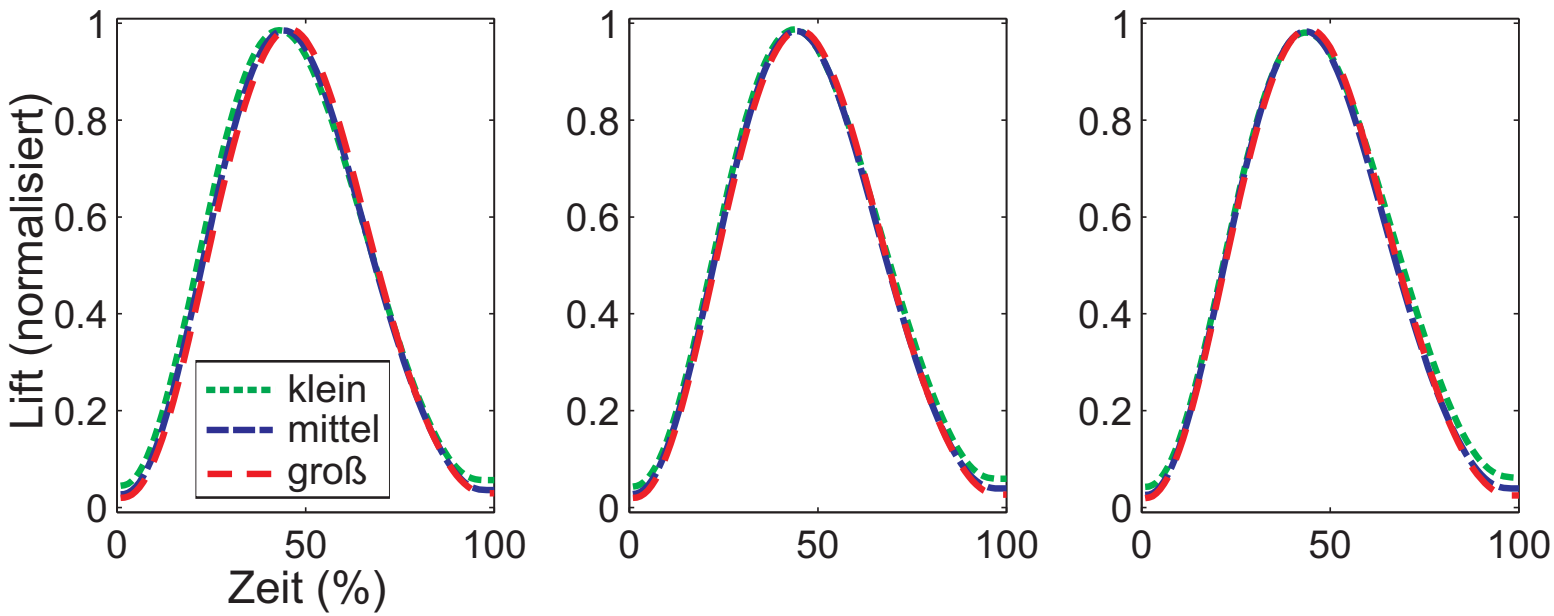
near

far

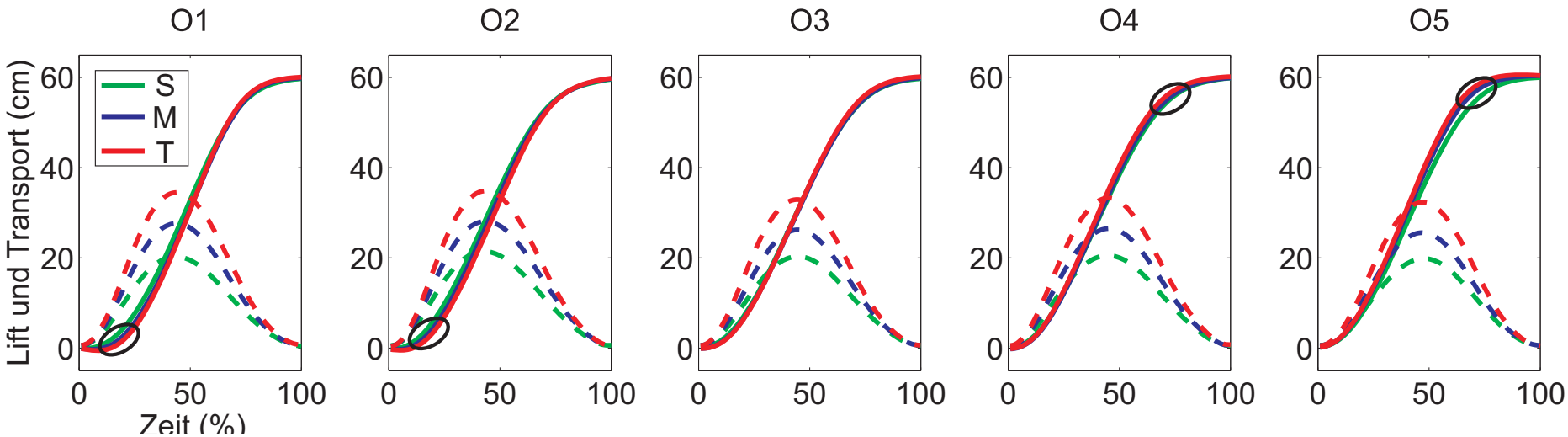
lift vs. transport

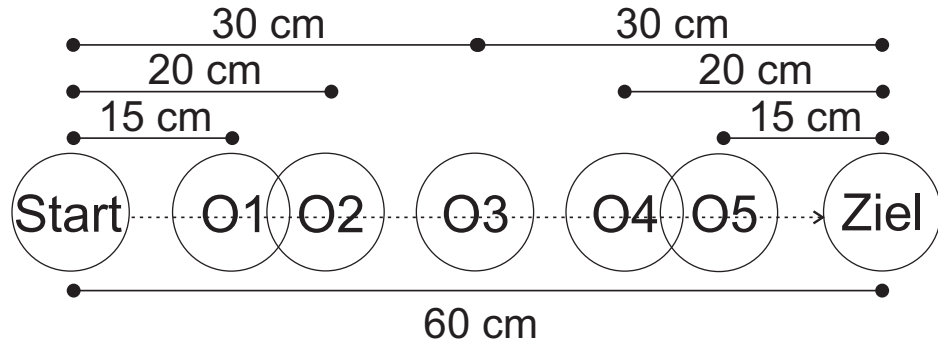


scaling lift to amplitude and time

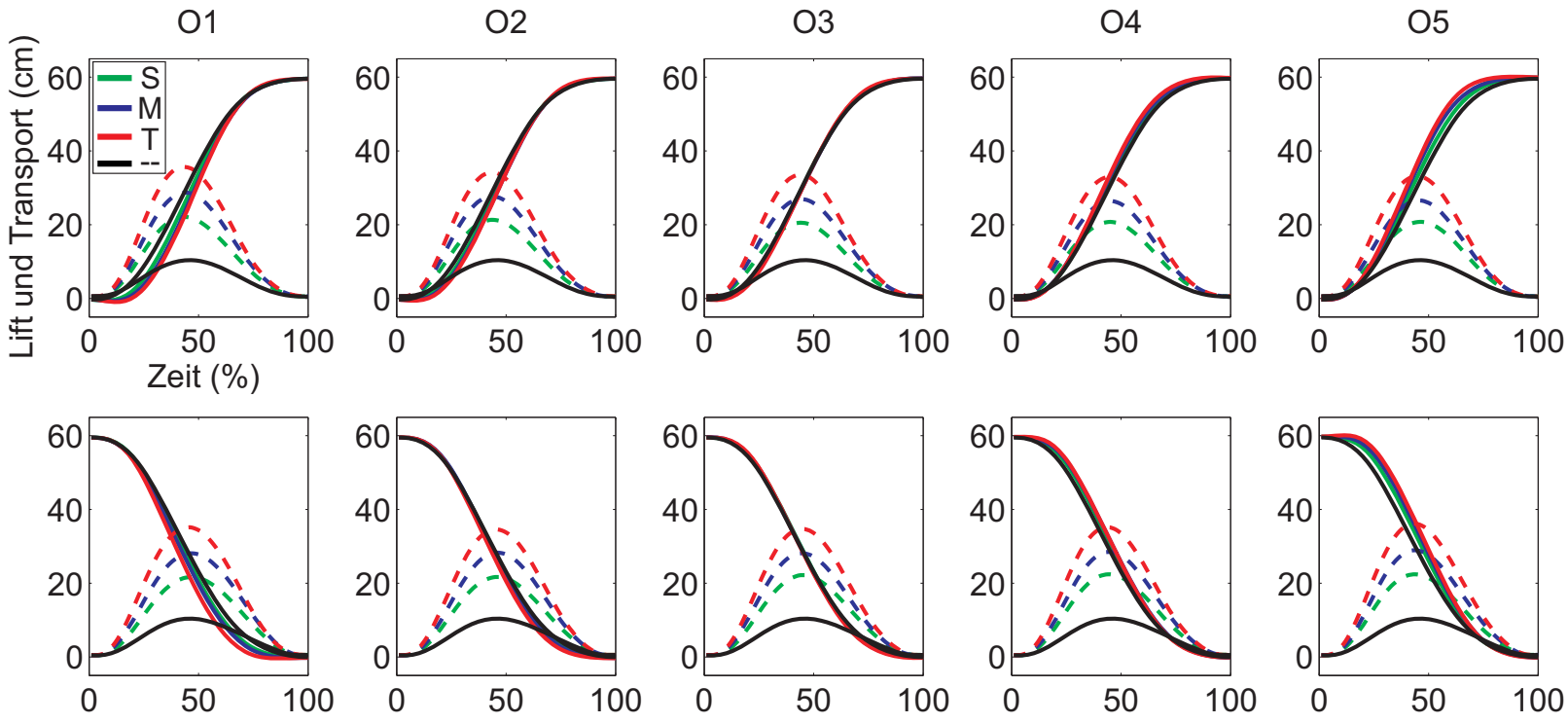


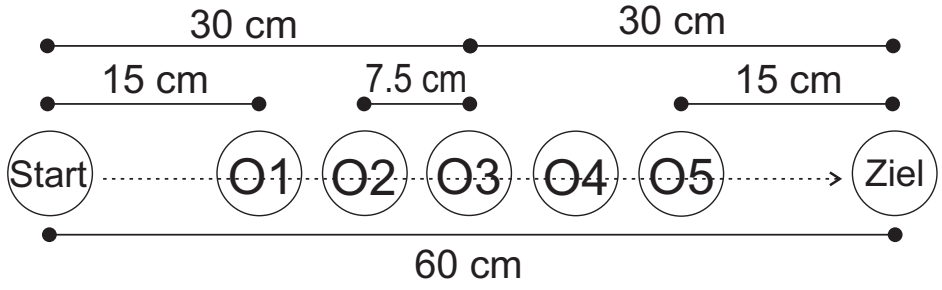
lift vs. transport





lift vs. transport

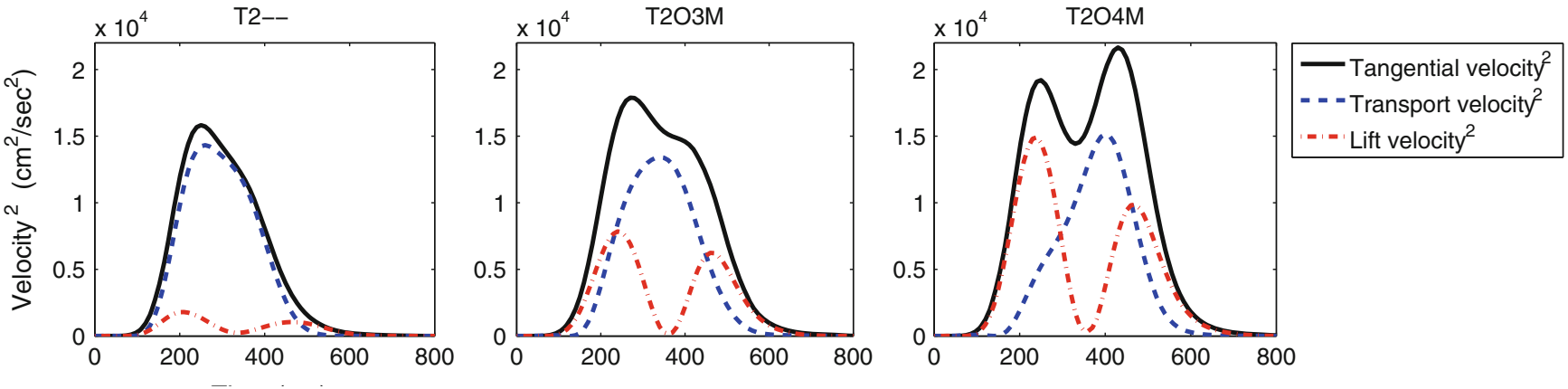


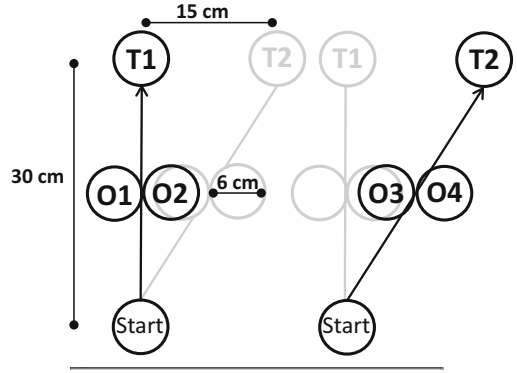


lift vs. transport

- invariance of lift under location of obstacle along transport
- approximate invariance of transport under height of obstacle
  - exact if obstacle is symmetrically half-way between start and target position of transport

complexity from simple components

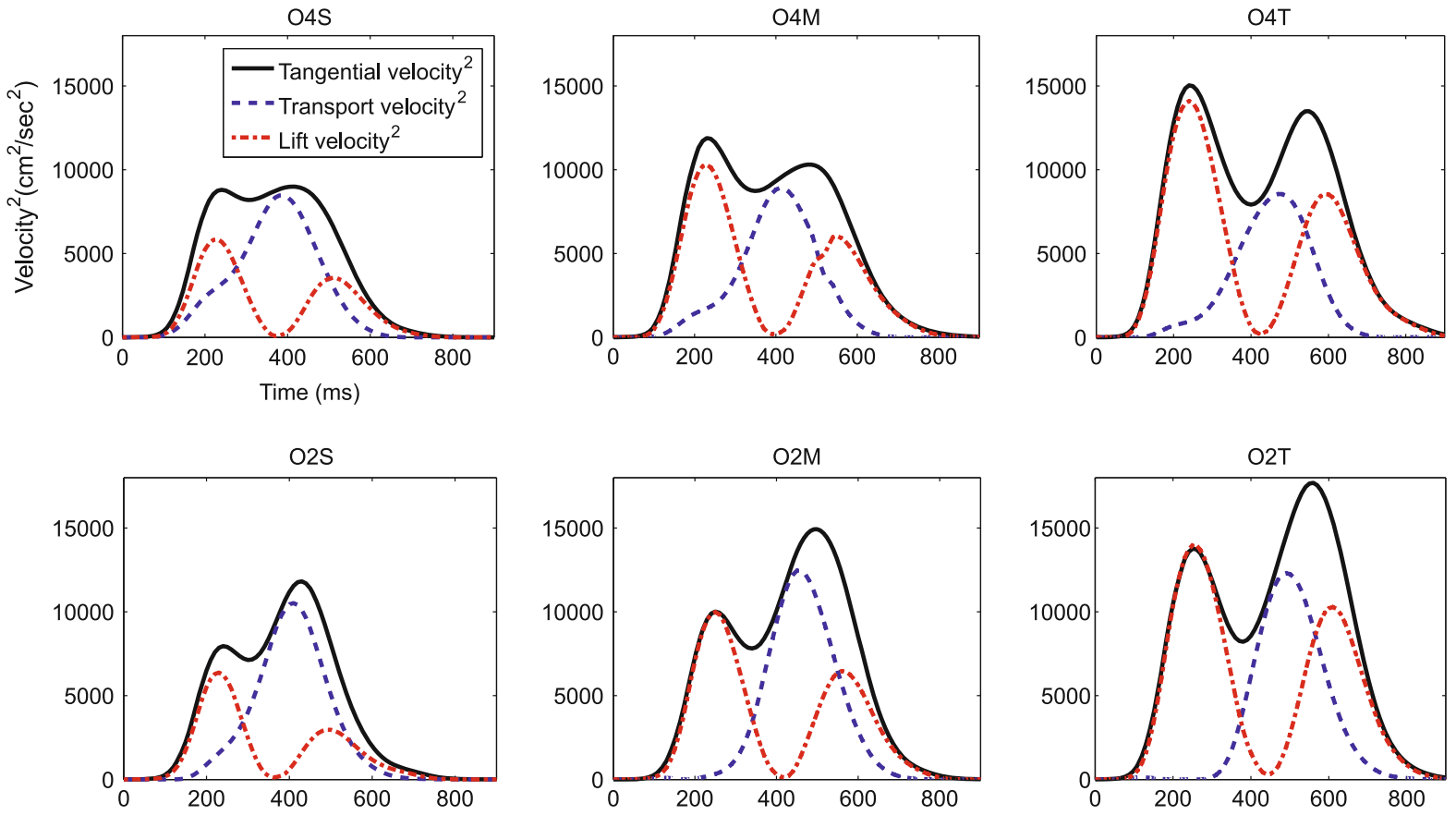


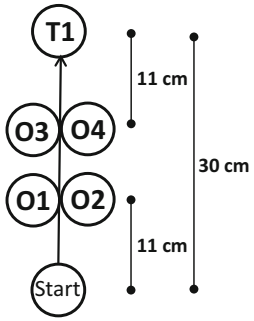


complexity from simple components

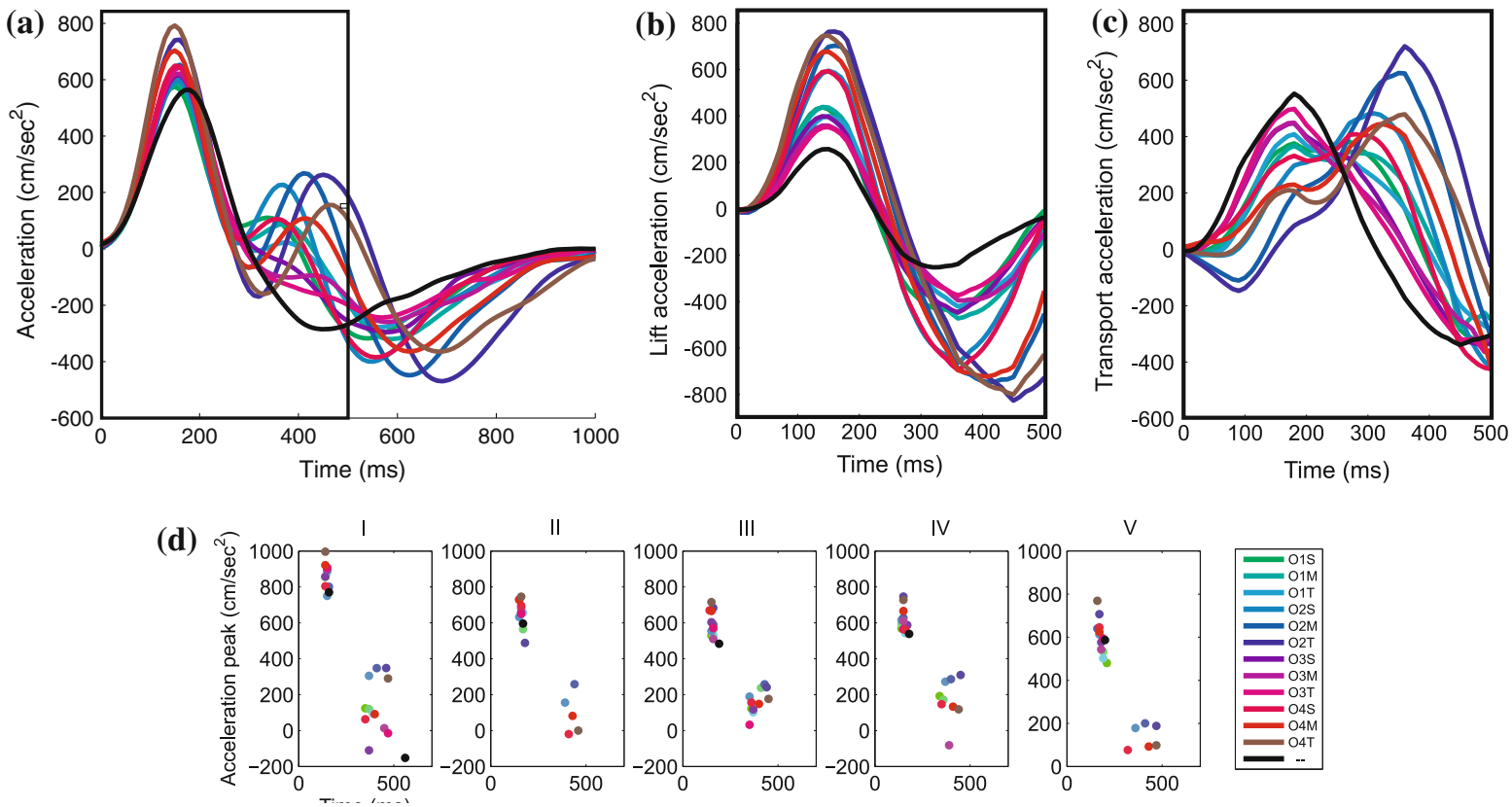
far obstacle

near obstacle





complexity from simple components



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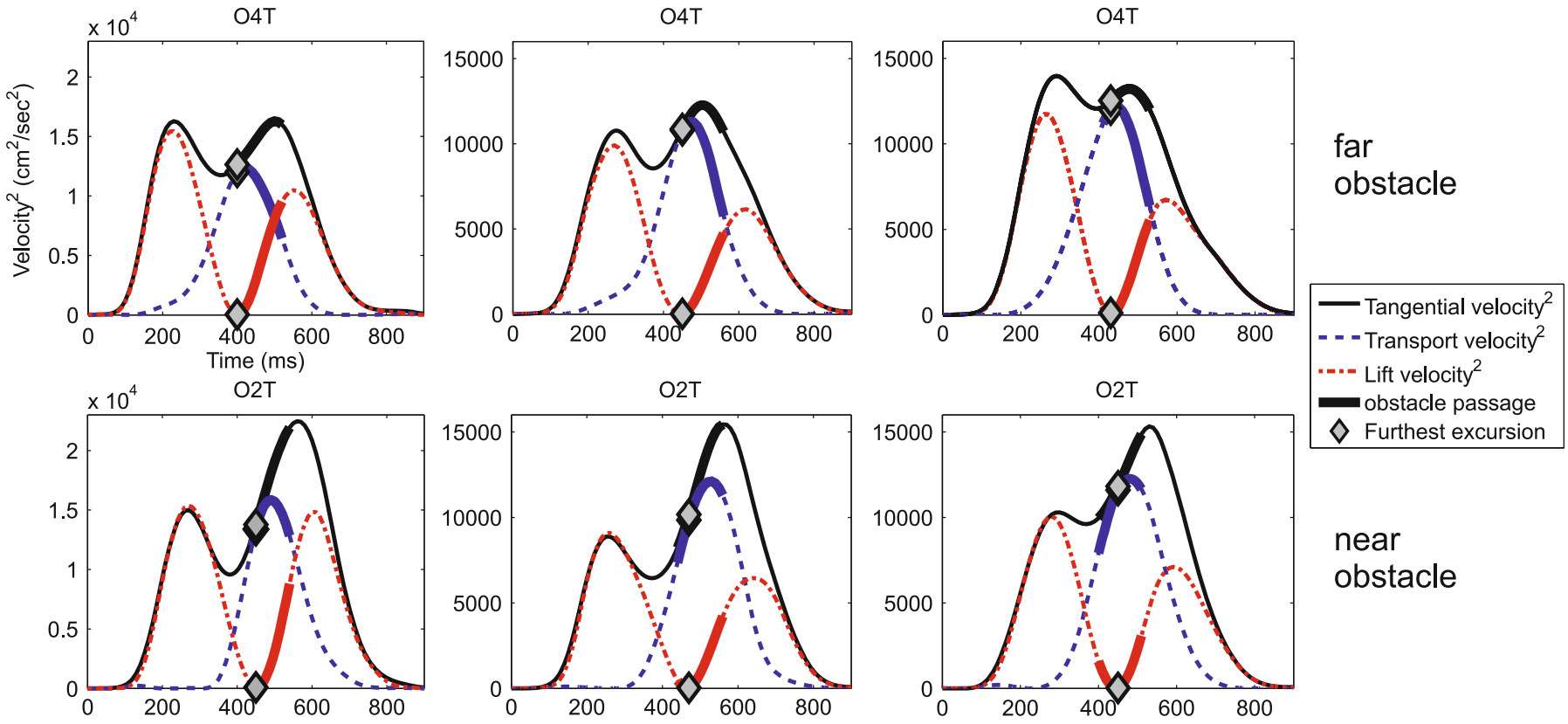
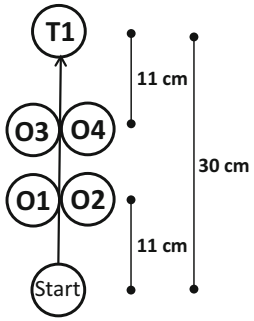
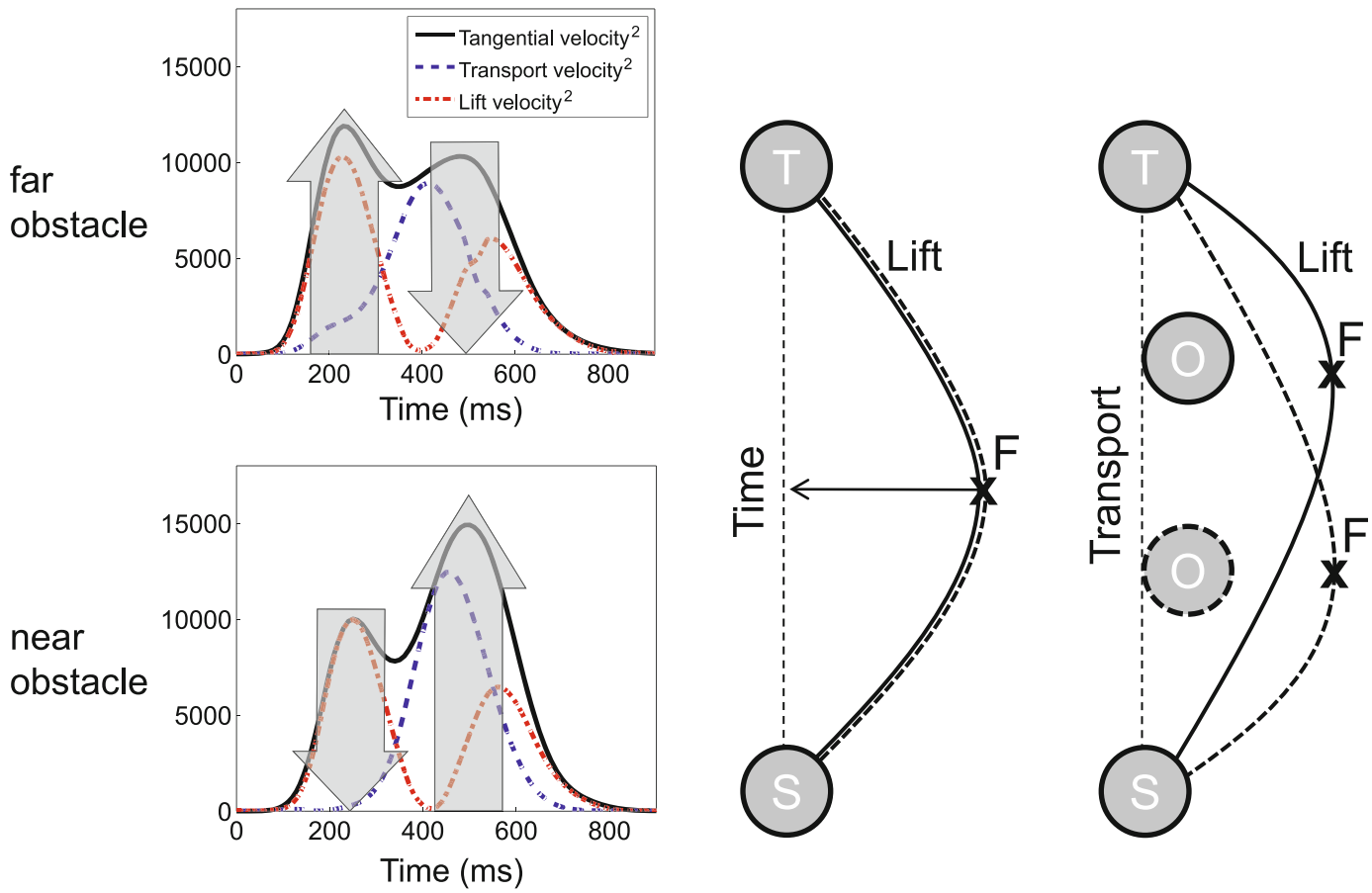
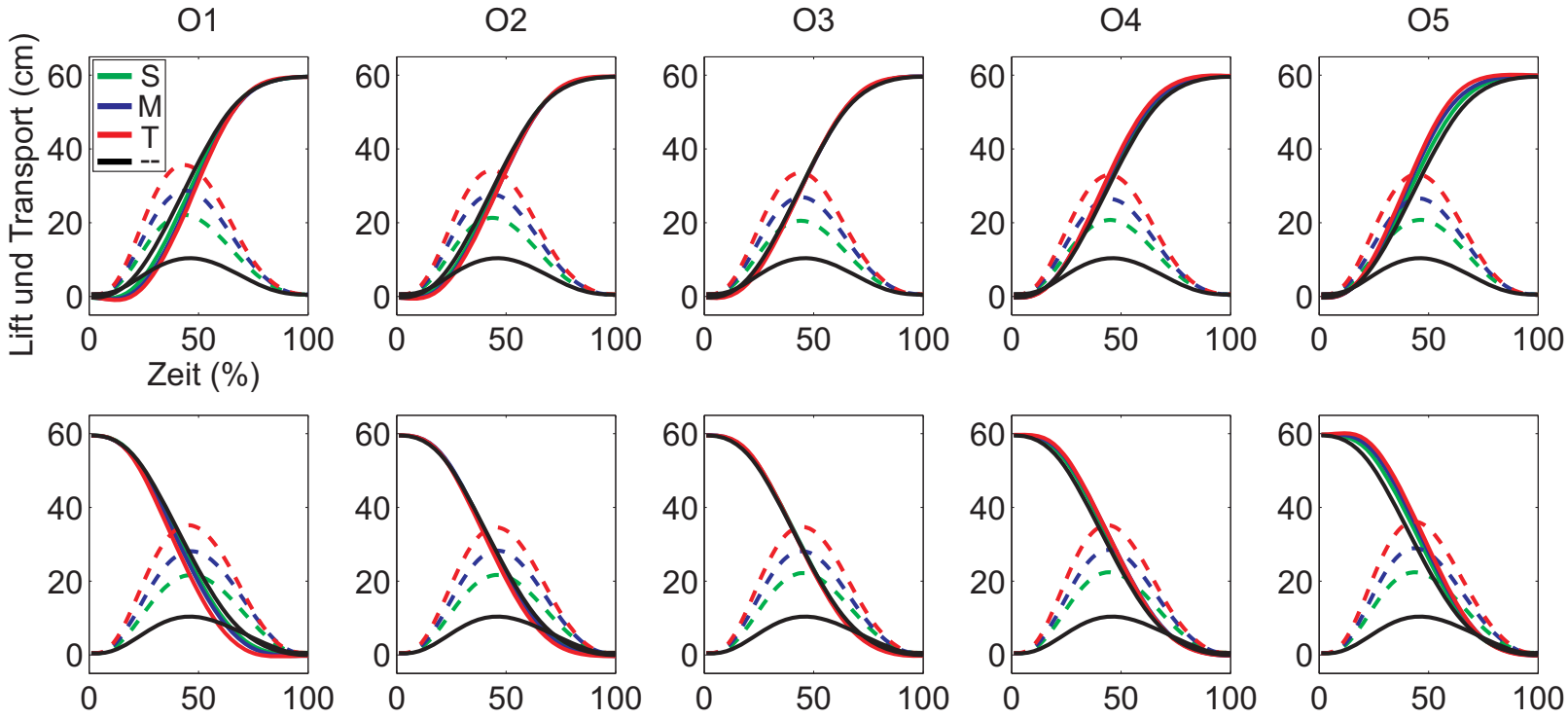


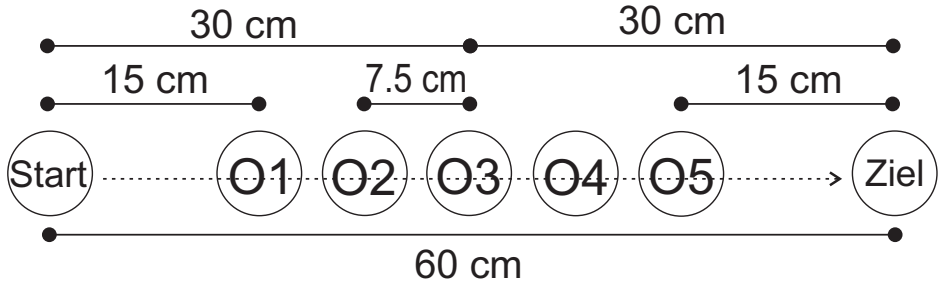


complexity from simple components

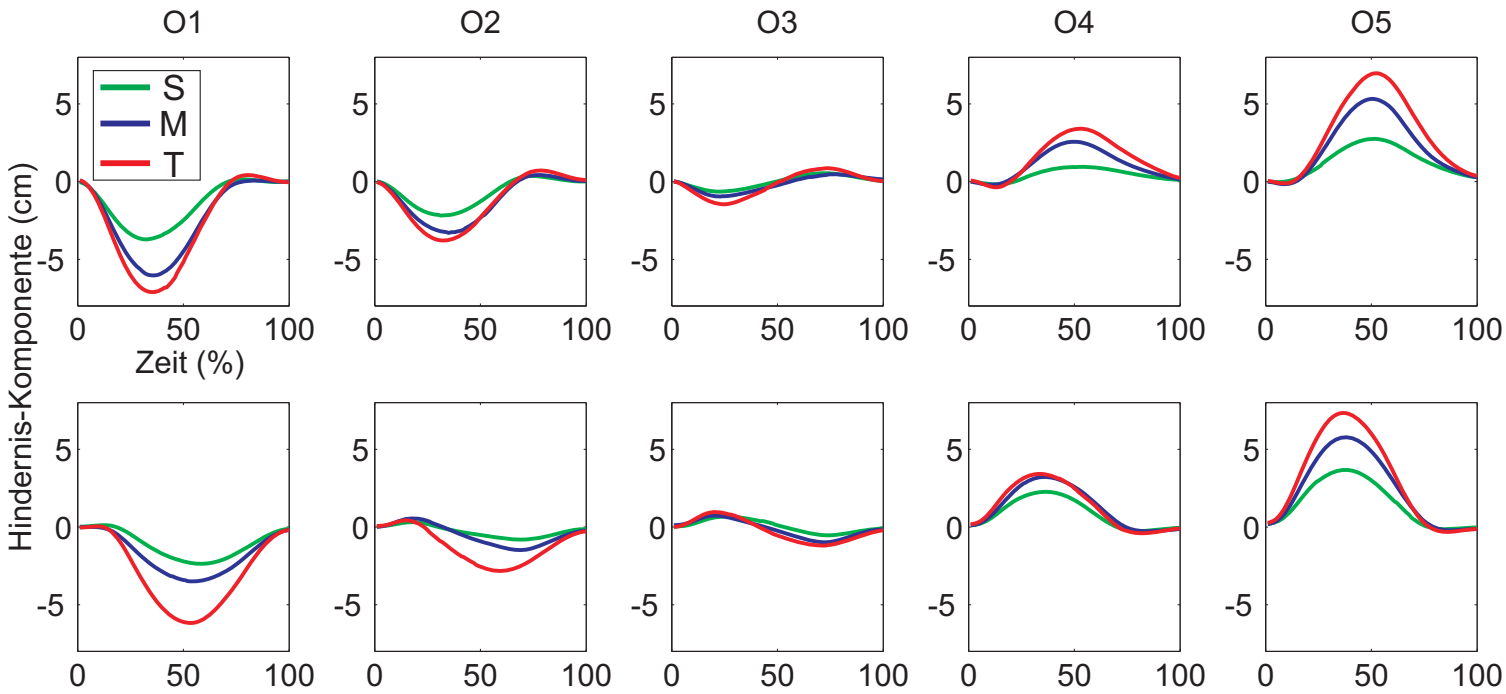


obstacle component





obstacle component



three types of invariance in movement

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- elementary behaviors
  - lift
  - transport
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