Trajectory perturbations during visually guided pointing: Tactile-kinesthetic detection, categorization and movement costs

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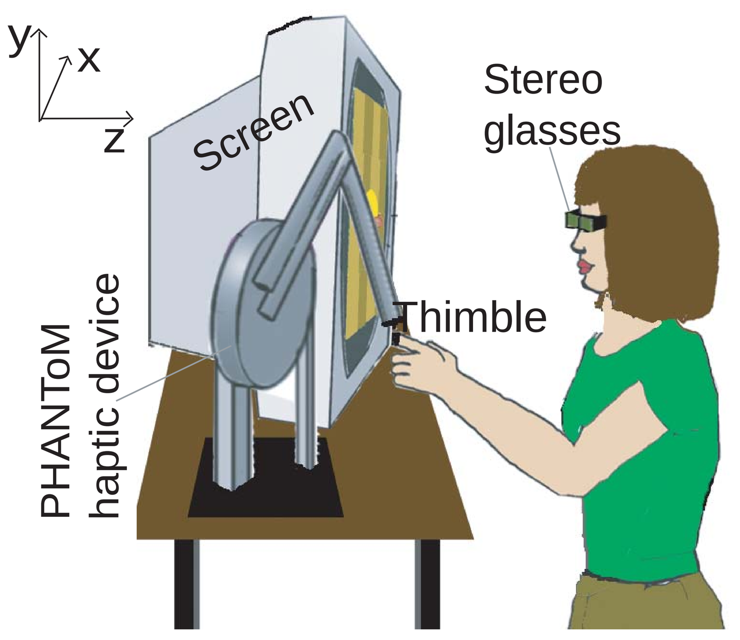
Introduction

During pointing vision seems to play a crucial role for movement execution, namely for online detection of and compensation for perturbations that interfere with the goal of the movement [1].

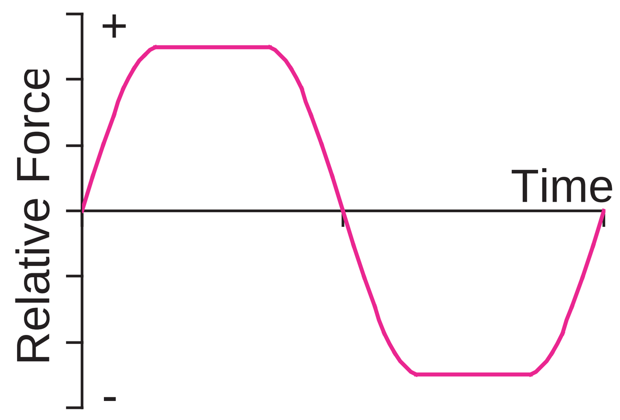
But, what if the trajectory is physically perturbed by a force during the movement and visual information is not available? Here, we asked whether tactile-kinesthetic cues alone suffice to detect and categorize external trajectory perturbations and how the perturbations interfere with the trajectory and the movement goal.

Methods

Visuo-haptic setup



Force perturbations



-orthogonally to movement

-specified by max. force, duration, direction in viewer plane

1. Detection task

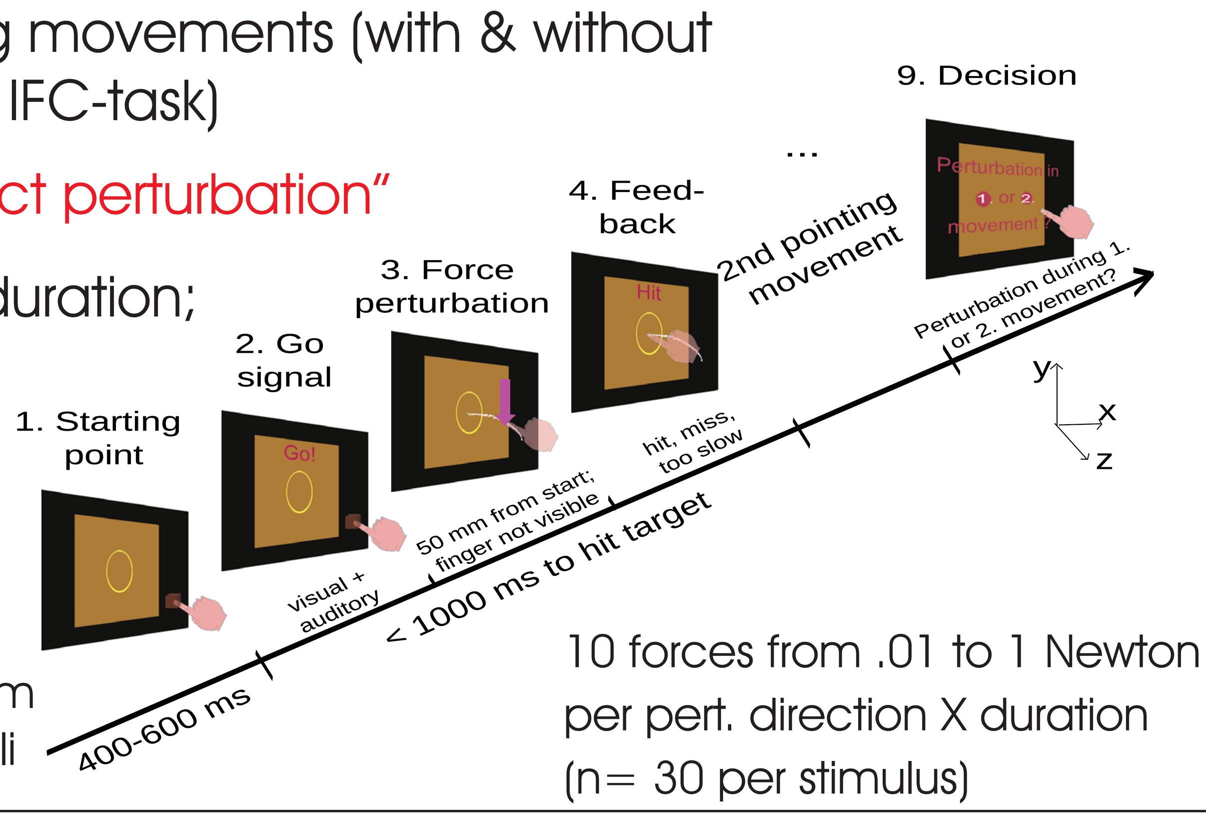
2 successive pointing movements (with & without force perturbation, 2 IFC-task)

"Hit targets and detect perturbation"

perturbation: 50 ms duration; 6 directions

perturbation: 30 ms; 3 directions

Detection thresholds from method of constant stimuli



10 forces from .01 to 1 Newton per pert. direction X duration (n= 30 per stimulus)

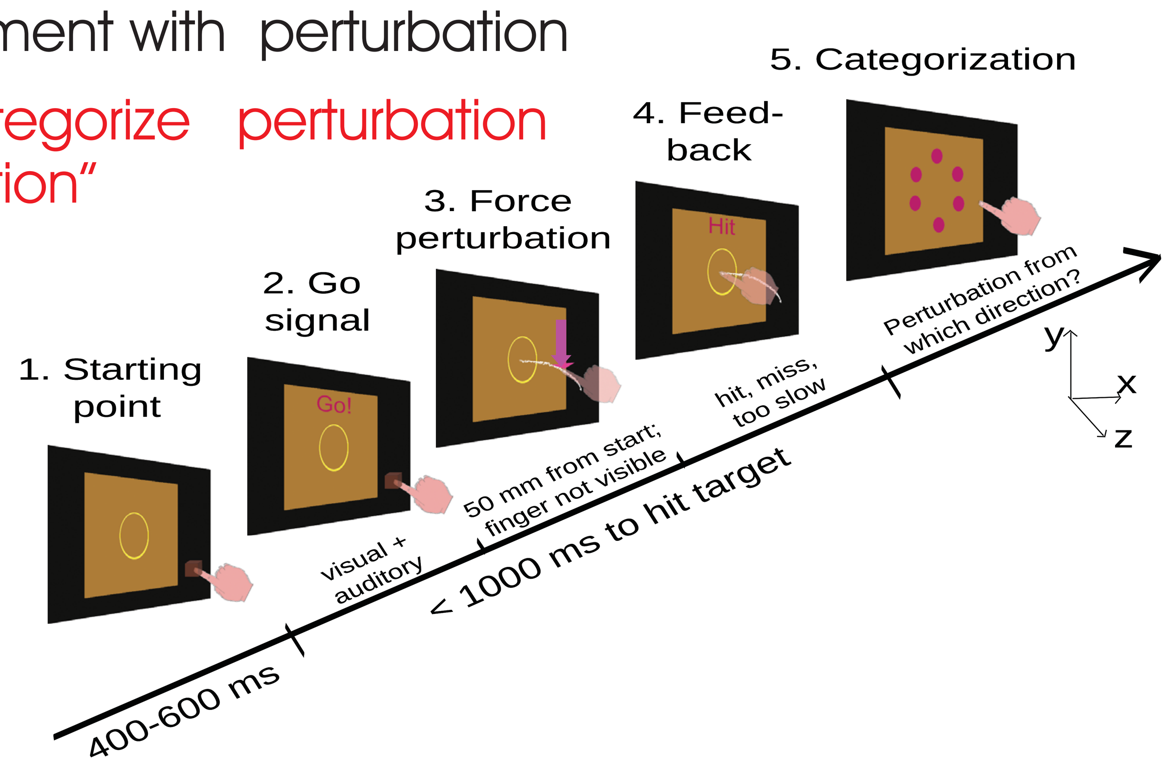
2. Categorization task

Single pointing movement with perturbation

"Hit target and categorize perturbation according to its direction"

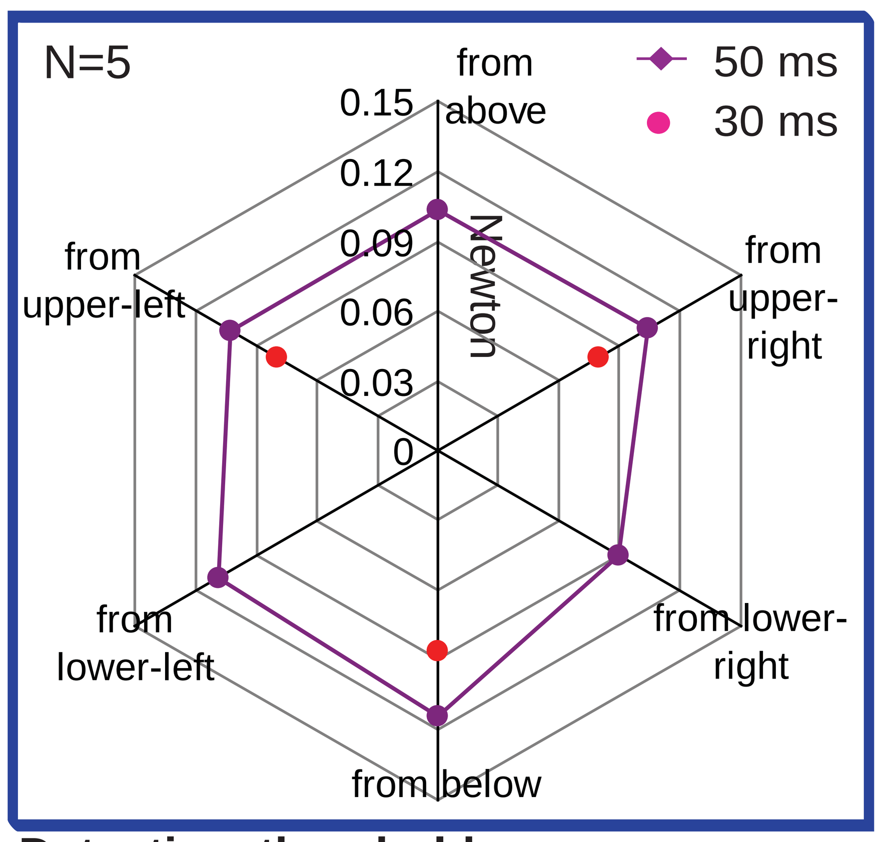
A: 4 pert. directions

B: 6 directions



Forces: .5, 1, 2, 3 Newton
Duration: 50 ms
n=100 per stimulus

Detection thresholds



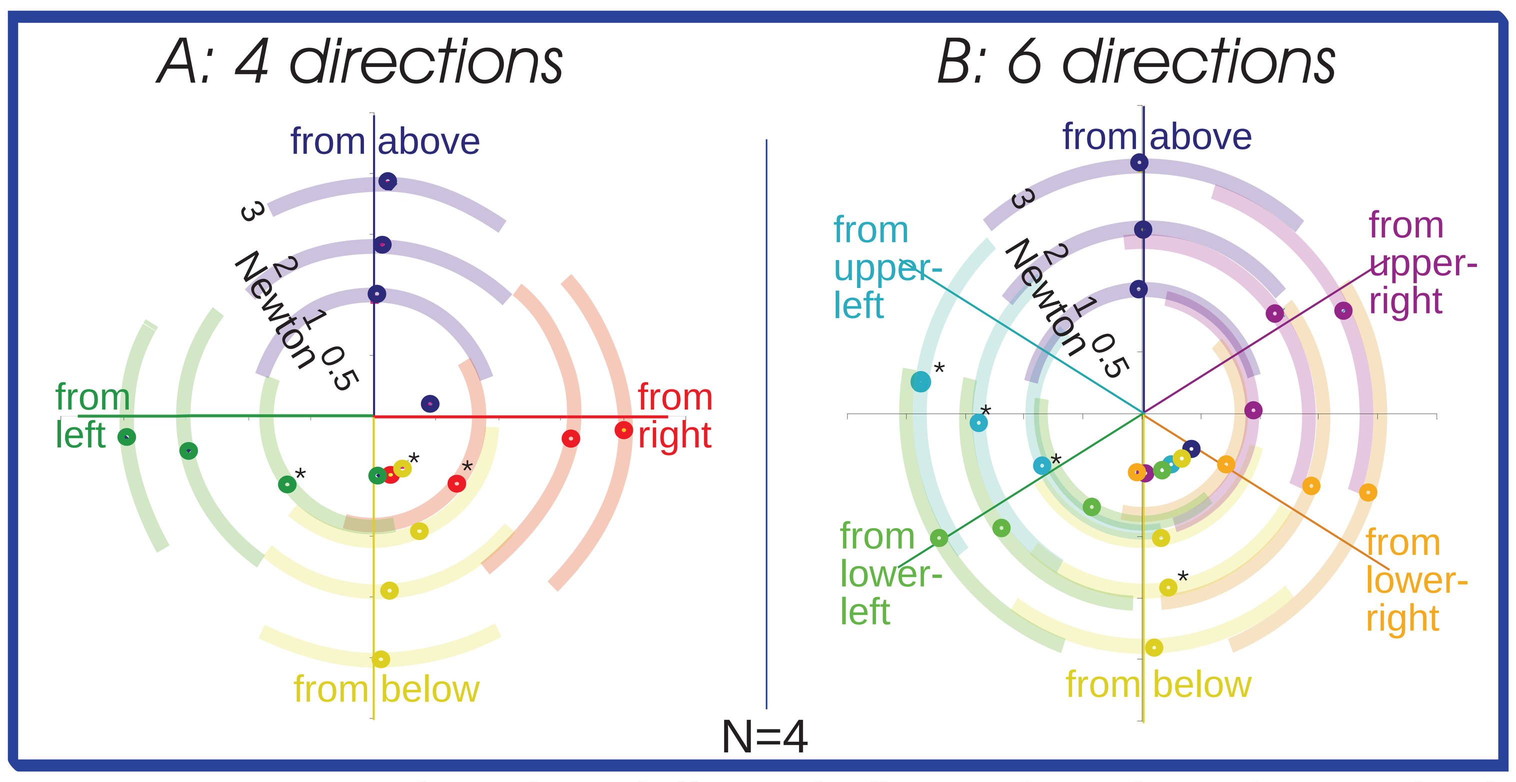
Detection thresholds (from individual ML-fits of psychometric functions, i.e. cum. Gaussians; [3]).

-No anisotropy ($p > .2$)

-Lower for 30 ms than for 50 ms perturbation ($p < .05$)

-Just slightly higher than for tactile detection of forces during a single-task (about .05 Newton; [2])

Categorization: Accuracy & Bias

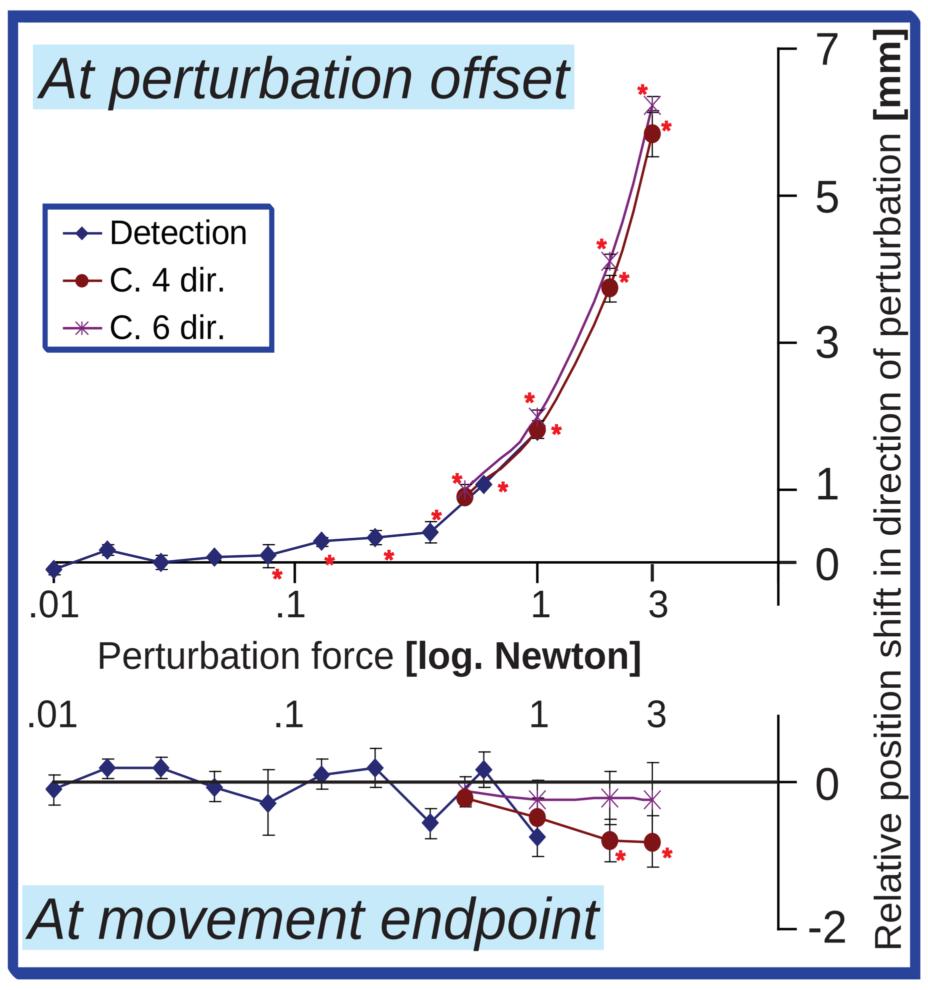


Mean responses and SD (spatially coded) as a function of perturbation direction (color coded) and force (from individual ML-fits of van Mises to response distributions).

-*Mean responses* in most cases not reliably biased (* = exceptions)

-*SDs of responses:* No anisotropy ($p > .2$), decrease with increasing force (p's $< .01$, down to ~40° for 3 N)

Movement costs



Relative shifts of finger position in direction of force perturbation (50 ms pert. only)

At perturbation offset:

-Reliable correlations ($p < .01$) of perturbation with position shift directions for forces > .046 N

-Considerable shifts of finger position up to 6 mm

At movement endpoint:

-No reliable correlations except for two cases (cat. 4 directions, forces 2 & 3 N, $p < .01$)

-Negligible shifts < 1 mm

Summary and conclusion

All subjects were able to detect and categorize trajectory perturbations using tactile-kinesthetic cues in isolation during visually-guided pointing movements. Surprisingly, the force of detected perturbations was just slightly larger than detection thresholds measured in a single-task context (~.05 Newton; [2]). Categorizations of perturbation direction demonstrated that direction perception, in the majority of cases, was veridical and, for forces >1 Newton, sufficiently accurate to distinguish reliably between major directions. The force perturbations altered the trajectories considerably. However, the distribution of movement endpoints at the visual target remained mostly unaffected. These results are a first hint that we efficiently perceive perturbations of pointing movements using only tactile-kinesthetic perception and without extra costs for the movement goal.

[1] Saunders, J and Knill, D. C. (2003) Humans use continuous feedback from the hand to control reaching movements, Exp. Brain Research , 152 (3), 341-52.
[2] Lederman, S.J. and Klatzky, R.L. (1999). Sensing and displaying spatially distributed fingertip forces in haptic interfaces for teleoperator and virtual environment systems. Presence, 8(1), 86-103.
[3] Wichmann, F.A., & Hill, N.J. (2001). The psychometric function: I. Filling, sampling and goodness-of-fit. Perception & Psychophysics 63(8), 1293-1313.

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