Illusory differences in movement variability and learning rates as a function of movement amplitude

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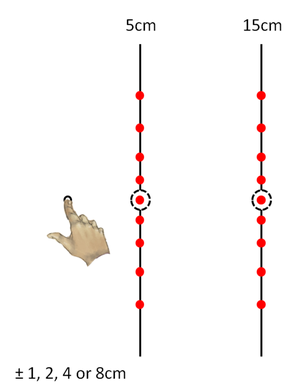
Background

A primary question in human motor control research is how the central nervous system detects and learns from reaching errors. This process is complicated by noise in execution that is not always constant or uniform relative to the hand in extrinsic space. Here we examine the distribution of variance in "shooting" and point-to-point reaching tasks along and orthogonal to the primary axis of motion when making reaches of different magnitude. We also test whether humans show differences in error sensitivity for these different lengths of reach.

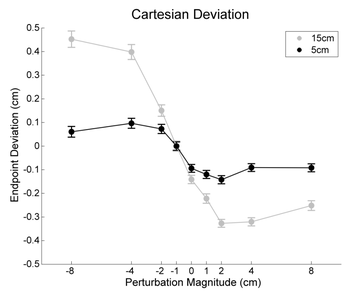
Learning & variance metrics are sensitive to coordinate frame

Wei & Körding (2009)



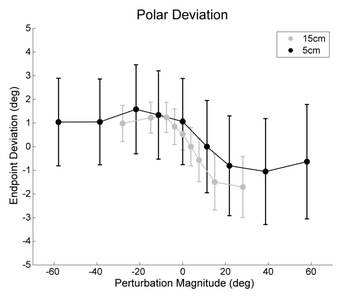
In this experiment by Wei & Körding, participants reached from a start point to a target either 5 or 15 cm distant. Endpoint feedback of the cursor was provided when the hand passed the target distance in the x coordinate. The cursor was pseudorandomly perturbed by ±0,1,2,4 or 8cm in sets of 9. The effect of these cursor displacements was measured by sorting all trials immediately following each perturbation, thus isolating the adaptive correction for each perturbation.

W&K in Cartesian



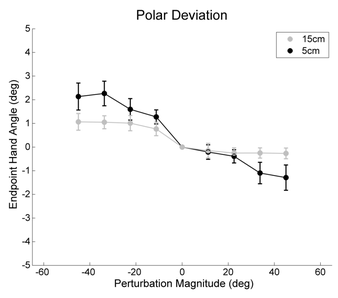
Here the hand position following each perturbation type is plotted for both groups of subjects. Both groups show a nonlinear discounting of large errors.

W&K in Polar

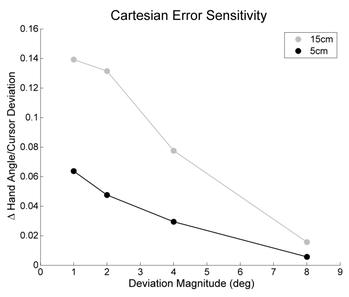


Same data as left, only converted to polar coordinates. The difference between the groups goes away in this plot because the corrections are scaled according to the reach length.

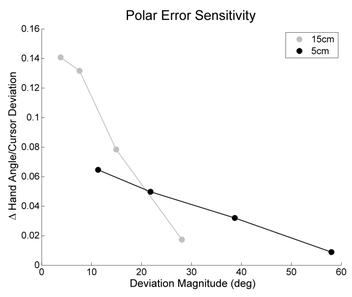
W&K Replication with matched perturbations



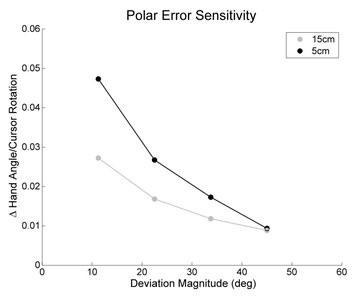
Our replication of the Wei & Kording experiment. The perturbations were matched in polar angle. The two groups adjusted to the perturbations similarly to the original experiment.



Here the absolute error sensitivity, or the correction divided by the error size, is averaged for both perturbation directions.

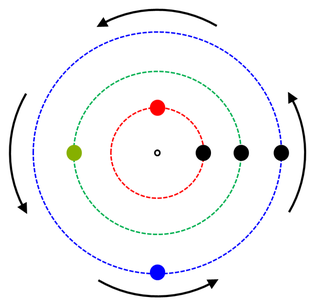


In polar space it is evident that the perturbations were of different size for the two groups. It is not clear that the 15cm group adjusts more readily to the same error.

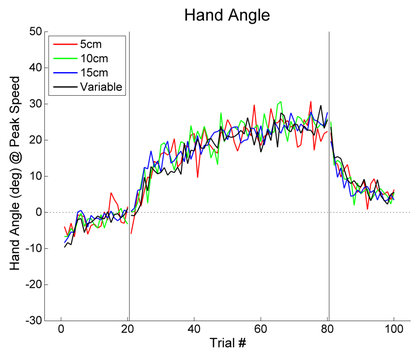


The 15cm group is not more sensitive to errors than the 5cm group.

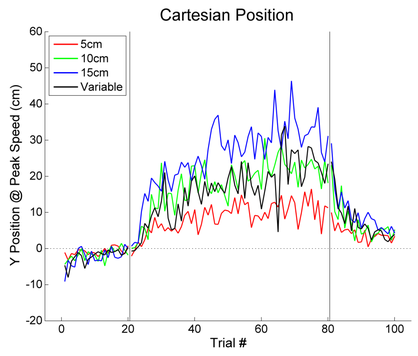
Center-Out Task



In this task participants made center-out reaches to one of four target directions. Each direction had one of three different reach lengths: 5, 10 or 15cm and one had all three distances in pseudorandom order. Each reach direction was sampled in pseudorandom permutations of the set of four reach directions. After a baseline block of 80 trials, there was a 240 trial abrupt 30 degree rotation block, followed by 80 trials of washout.



Endpoint hand angle for each reach distance is plotted independently to show any differences that may be due to reach magnitude. It is clear that all three reach distances show identical adaptation rates, asymptotes, and aftereffects.

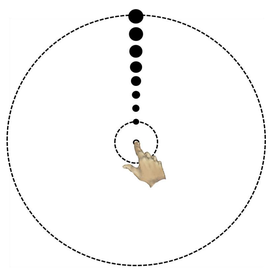


The same reach data, but plotted in Cartesian coordinates. These differences, although real, are clearly the result of the chosen coordinate frame.

The axes of endpoint variability are differentially scaled by reach length

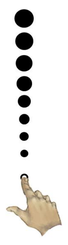
Shooting Task

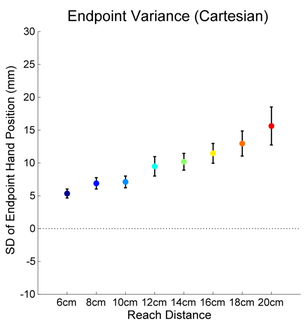
Participants made a total of 600 "shooting" movements to targets at 8 pseudorandomly ordered distances, ranging from 6-20cm. Visual feedback of hand position was not provided. Visual target size changed at each distance so that it always spanned 3 degrees in polar space.



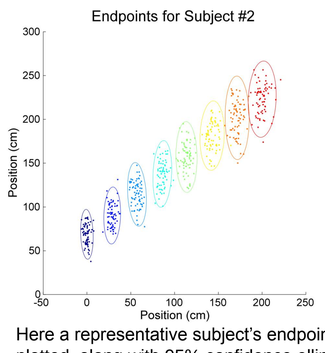
Point-to-Point

Participants made pointing movements attempting to stop on the visual target. No visual feedback of hand position was provided. Visual target size and order of presentation were the same as the shooting task outlined at left.

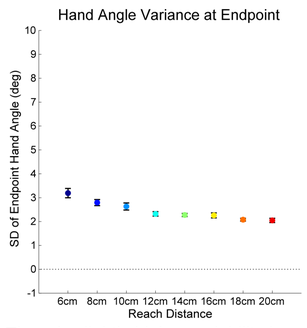




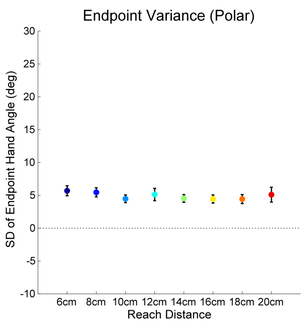
Endpoint variability upon passing the target distance. This variability, orthogonal to the primary direction of motion, increases linearly with reach distance.



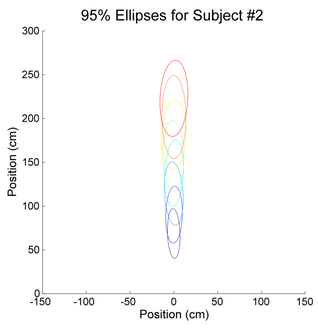
Here a representative subject's endpoints are plotted, along with 95% confidence ellipses. Each target is offset slightly for visualization purposes.



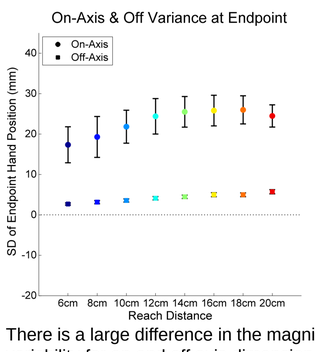
There is slightly higher variability in polar space for short reaches, and this decreases with reach length.



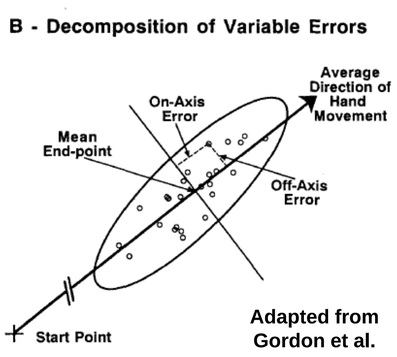
When the same data is converted to polar coordinates, theta remains constant across all reach distances.



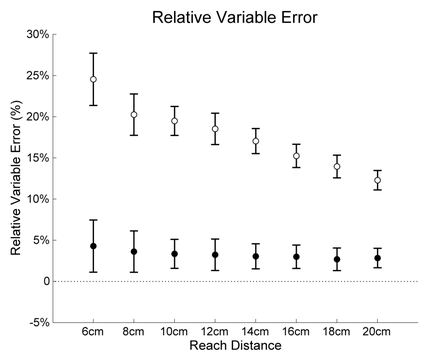
95% confidence ellipses for the same subject, plotted at the mean clustering of endpoints for each reach distance.



There is a large difference in the magnitude of variability for on and off axis dimensions. Note that On-axis variance tapers off.

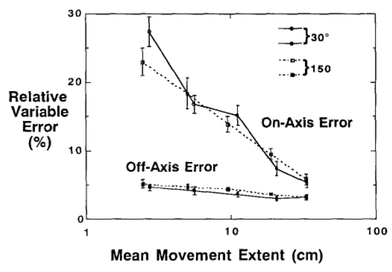


Adapted from Gordon et al.

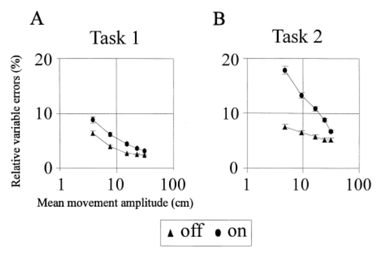


Plotted here is the on and off-axis variance scaled by mean reach distance. If variance along a given axis is constant relative to reach magnitude, this will be a flat line. We observed a large difference between the two axes. On axis relative variance started high for short reaches and decreased at larger distances, while off-axis relative variance remaining around 5% for all reach distances.

Previous Work



Gordon, Ghilardi & Ghez (1994)

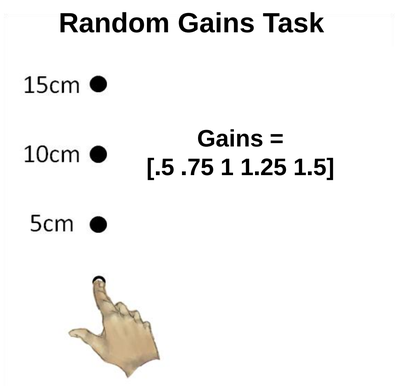


Messier & Kalaska (1997)

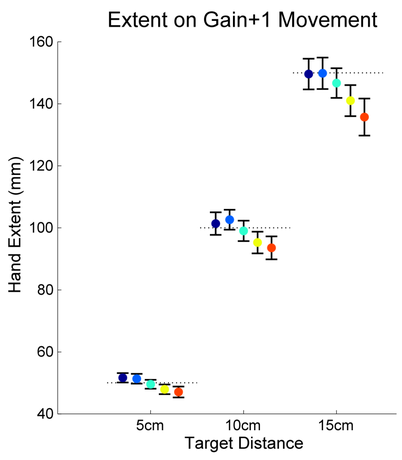
These two experiments found differing results when experimental conditions moved from viewing the hand and targets on a real table versus a virtual display on a vertical monitor. In particular the increased relative variable noise for the on-axis dimension was attributed to errors introduced by planning reaches in the abstract vertical plane. Our experimental setup is a hybrid of these two experimental conditions, so the predicted contribution of on and off-axis relative noise was unclear and needed to be tested directly. Interestingly we found the same effect that arose from the vertical screen condition.

Error sensitivity for gains scales across reach amplitudes

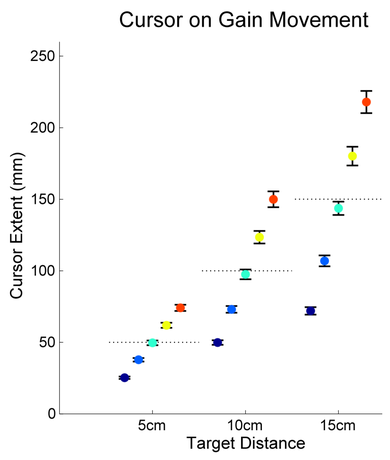
Random Gains Task



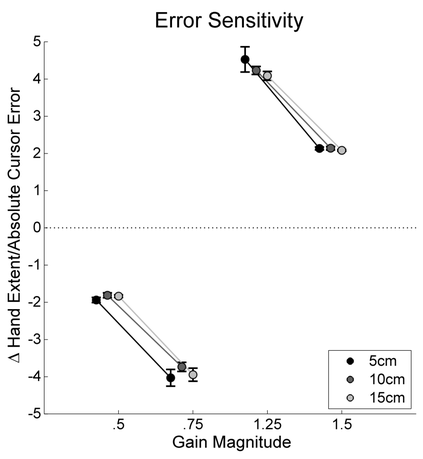
In this task participants reached to one of three targets for two hundred trials each, in a counter-balanced order. While reaching at a given distance, one of five pseudorandomly selected gains ranging from .5 to 1.5 was applied to the cursor. The mean cursor displacement for every five trials was 0, or no perturbation. The primary behavioral measure was change in endpoint hand extent on the trials following a given gain.



Mean hand position for all three target distances. Adaptive corrections are not linearly proportional to error size, although the size of corrections is larger at longer reach distances



Actual cursor positions for each gain trial. Note how much larger gains are for 15cm reaches compared to 5cm.



When adaptive corrections are divided by error size, there are no differences between corrections for different reach lengths. There is, however, a clear discounting of large errors relative to the reach distance.

Summary

- Variance orthogonal to the primary axis of motion is roughly constant if scaled appropriately
- Variance along the primary axis of movement dwarfs orthogonal variance
- Adaptation to perturbations both along and orthogonal to the primary axis of motion are scaled to reach magnitude
- The motor system discounts large errors in both direction and extent