What do pointing errors really tell us about internal coordinate transformations?

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The target article by Flanders et al. summarizes extremely elegant work which derives a series of unexpected and most interesting results from very simple experiments. We think the results provide good evidence that the nervous system behaves as if several different coordinate systems are used in converting visual target information into arm movement. It may at first seem surprising that the movement appears to be organized in a coordinate system centered at the shoulder, and it is puzzling that the representation in this system is better for one parameter, finger distance, than for others, finger direction; however, the trick of transforming positions into coordinate systems at the base of limb segments is one practiced by the many recursive algorithms for robot control. We also agree with the authors that an important challenge for the future will be to elucidate how these transformations are performed by the nervous system.

Despite this general agreement, we would like to voice a note of caution against overinterpreting the results. Our concern is based on limitations in the experimental paradigm which, in our view, require some further investigation. In particular, it focuses on the nature of the coordinate transformations and the question of whether movement or end-position is actually being planned.

The most impressive and at the same time surprising result in our opinion is the nature of the absolute error in final finger position when pointing in the dark compared with pointing in the light. The regression analysis of this absolute error leads Flanders et al. to conclude that this deviation results from an inexact coordinate transformation from the shoulder-centered extrinsic frame of reference based on target distance, azimuth, and elevation into the intrinsic frame of reference based on the elevation and yaw of upper and lower arm. They further conclude that this deviation arises because the brain implements a simple, linear approximation to the true nonlinear relationship required for accurate pointing. Because the data concern only final arm position, the implication is that the brain has a single, invariant transformation for mapping desired finger positions into arm configurations.

We would like to suggest that only a part of the absolute error is the result of this distortion in the coordinate transformation; errors in controlling the pointing movement itself rather than the final position may also contribute. In the discussion of one original paper (Soechting & Flanders 1989a), the authors cite published reports showing that the length of a targeting movement is correlated with the amount of undershoot, but they conclude that the contribution this factor makes to the measured absolute error is small and can be neglected. Preliminary experiments by one of us (H. C.) indicate that the absolute error in the final position can be significantly influenced by the amplitude and the direction of the pointing movement. In these tests, four subjects were asked to point from one of two starting positions to four virtual targets all located on a horizontal plane about 15 cm below the shoulder of the subject. The four targets and the two starting positions were arranged at 10-cm intervals in a line in the sagittal plane. The starting positions were at the two ends. Thus, the subjects had to move to the same target from two opposite directions. Figure 1b shows the absolute error for each target for movements from the near starting point (open circles) and those from the far starting point (closed circles). Movements from the near starting point correspond qualitatively to the situation studied by Flanders et al. and so do the results. In fact, for both series, the magnitude of the deviation in the direction of the shoulder increases with the distance of the target from the shoulder. This finding qualitatively supports the hypothesis of a distortion in the coordinate transformation, although more data and a regression analysis are necessary to test the quantitative agreement.

All four mean values for pointing movements beginning distally, however, lie above the corresponding mean values for those beginning proximally (this relationship also holds true for the mean values of the individual subjects). Thus, final position is significantly influenced by the starting position of the hand. A careful look at the dynamics of pointing is accordingly needed before all of the absolute error can be attributed to the simple linear transformation for determining final arm configuration – the explanation Flanders et al. propose. One simple explanation for this second component in the absolute error is that the movement is carried out under the influence of a proportional controller. Starting position does not have a significant influence on final arm configuration when visual feedback is available, even when the arm configuration is not uniquely determined by the finger position (Cruse 1986) and simple neural networks can learn the corresponding mapping function (Brüwer & Cruse 1990), so under other conditions it does appear that the brain uses simple algorithms for mapping finger position into arm configuration.

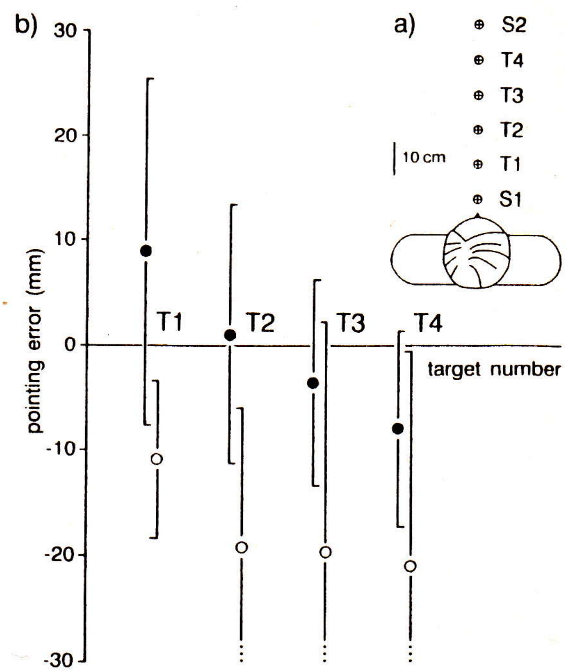

Figure 1 (Cruse & Dean). (a) Top view of the positions of the two starting points (S1, S2) together with the four target points (T1–T4). The distance between neighboring points is 10 cm. (b) Mean absolute error between target and actual finger position for four subjects pointing to each target starting from S1 (open circles) or S2 (closed circles). Absolute error is measured as the distance from the target in the sagittal plane; negative deviations correspond to errors in the direction of the shoulder. After viewing the target, the subject performed the movement with the eyes closed. The bars indicate one standard deviation.

A second point where we feel caution is required before generalizing too freely concerns the separation in the channels subserving arm elevation and yaw. Here too it seems to us that the nature of the required movement influences the measured deviation in final position. A priori it would seem that a pointing movement beginning with the arm lowered at the side is most economically performed by raising the arm in the plane with the required azimuth. Models of arm movement in which one component strives to reduce unnecessary or counterproductive movements at the various arm joints produce good approximations of simple target movements (Cruse & Brüwer 1987). Thus, it is not surprising to find that the yaw of the arm depends on target azimuth but not on elevation and distance. However, when the arm initially lies in a horizontal plane (e.g., on a table), the yaw in the final position will depend strongly on target distance as well as azimuth and for other starting configurations we suspect it will depend on varying combinations of target azimuth, elevation, and distance. Thus, our best guess is that any separation of channels may need to be redefined in terms of the plane of the arm. A similar influence of starting position or required motion may also confound some of the matching experiments cited in support of the separation of channels.

Despite these qualifications, we would emphasize that the experiments of Soechting and his colleagues provide several tantalizing results and a good, quantitative hypothesis for testing. Thus, they provoke numerous further experiments and that is certainly one measure of good research.