Abstract

Historically, research in motor control has emphasized hit/miss ratios and time-to-target as primary performance metrics for reaching and tracking tasks. While these methods may be suitable when the operator's intent to hit the target is known, they provide less confidence when the intent of the operator is unknown or unmeasurable such as when studying motor behavior in animals. We studied the performance of a random process in a two degree-of-freedom reaching task. A cursor was advanced with a uniform radial velocity where the angle of each successive movement was chosen from a uniform distribution. If the target was hit, a "success" was recorded; exceeding a time-limit resulted in a "failure." This procedure mirrored a reaching task in another study where primates moved a cursor to a target, first using a manipulandum and later by "brain control". Under these constraints, random process performance depended only on radial velocity and hit targets under 50% of the time. Other performance metrics were tested, including a measure of movement inefficiency and a measure of the allocation of control. We propose that intent in a controller can be shown by its out-performing a random process. To test this, a simple model of a controller with intent was created by generating a random walk but biasing the distribution of possible movement angles toward the target location. The performance of this controller and that of a behaving primate was contrasted with the target-blind random walk for the above performance metrics.

A Random-Walk Analysis for the Evaluation and Design Motor Control Tasks

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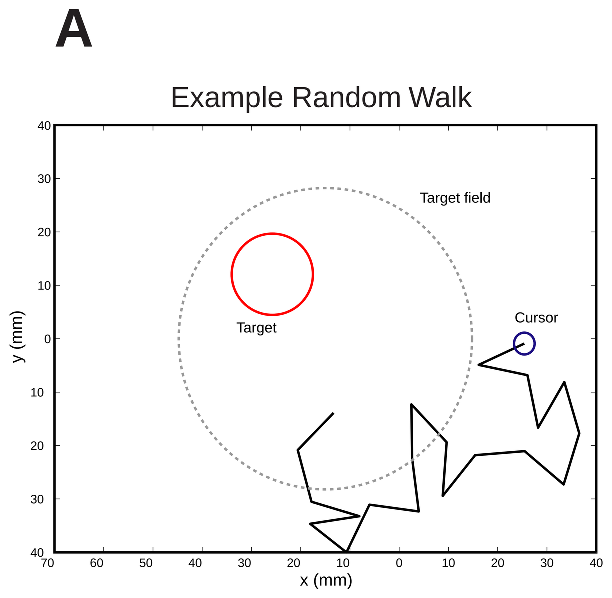
Background

The motivation of this work is a study [1] where primates were trained to move a cursor to a target in a 2-dimensional space by movement of a manipulandum. Simultaneous to the task, the activity of several cortical regions were monitored by extracellular electrodes. After sufficient training, the manipulandum was disconnected and cursor position was governed by brain activity alone, a mode known as "brain control." A significant problem with such a paradigm is how to determine that any subsequent movements were intentional on the part of the animal and thus meaningful.

Random Walk

Our approach was to model an intentionless controller as a random walk constrained in the same fashion as the experimental task. A 2 mm cursor was gien a random initial position on a 110 mm by 80 mm field. Likewise, an 8 mm target was given a random initial position on the same field, but constrained to within a circle with a radius of 30 mm. The cursor and target were separated by a minimum distance of 10 mm at the start of each trial. The cursor was made to move with a constant radial velocity. A new movement direction was drawn every 100 ms from a uniform distribution on $[0,2\pi]$. The target was "hit" if the cursor was at any time fully inside the target. A "miss" occured if the target was not hit after 10 s.

A



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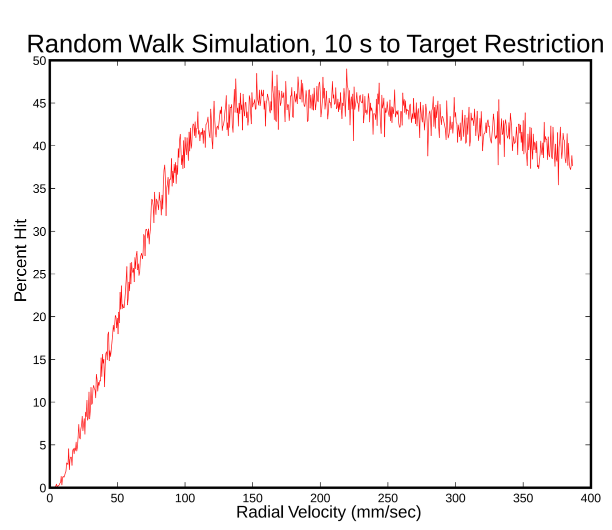


A. Cartoon of the simulated paradigm. B. Percent targets hit by the random walk as a function of radial velocity, 1000 iterations.

Performance Metrics

Three performance metrics were used to measure coordination: (1) Percent target hit within time-limit, (2) Inefficiency of path, and (3) Allocation of Control. Inefficiency of path, described in detail by Zhai [2], is expressed as the ratio of actual and optimal paths. Allocation of control (or M-metric) as described by Masliah [3] is a measure of the simultaneity and efficiency of control. The equations for inefficiency of path and M-metric are given below in C and D respectively.

C

$$inefficiency = \frac{actual - optimal}{optimal}$$

NERF is the normalized error reduction function; SOC is simultaneity of control; EFF is efficiency of control.

D

$$NERF_i(t) = \begin{cases} -dE_i(t) * \frac{1}{ACT_i}, \text{ for } \dot{E}_i < 0 \\ 0 \text{ for } \dot{E}_i \geq 0 \end{cases}$$

$$SOC = \int_0^T Min\left(NERF_1(t), NERF_2(t), \ldots, NERF_3(t)\right) dt$$

$$W_i = \frac{k}{n} * \frac{OPT_i}{\sum_{j=1}^{k} OPT_j}$$

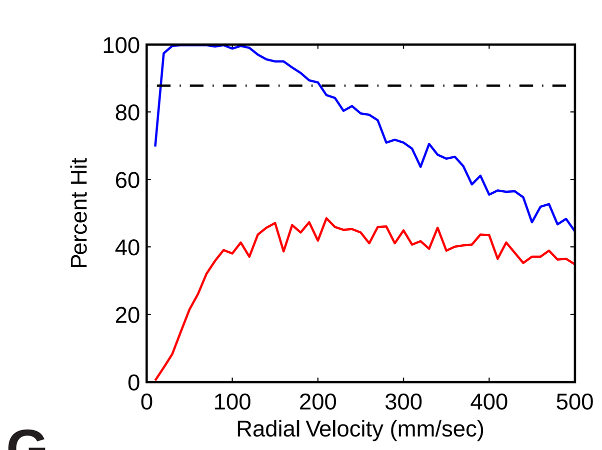
$$EFF = \sum_{i=1}^{n}\left(\frac{OPT_i}{ACT_i} * W_i\right)$$

$$M = SOC \times EFF$$

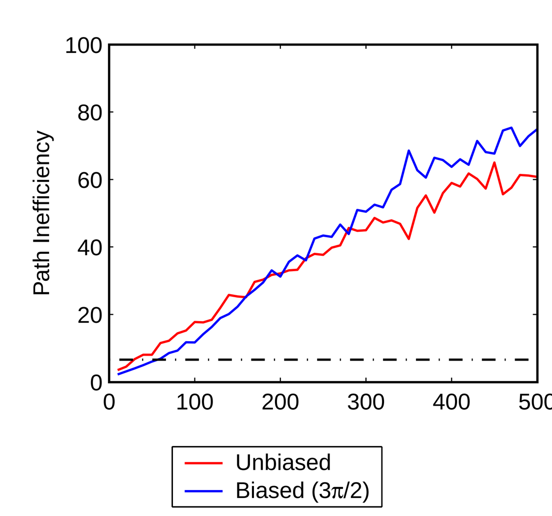
Intent was modeled by biasing the distribution from which each random radial step was drawn in the direction of the target. In this way, while the process was still moving randomly, it had some "knowledge" of the target location.

Comparisons

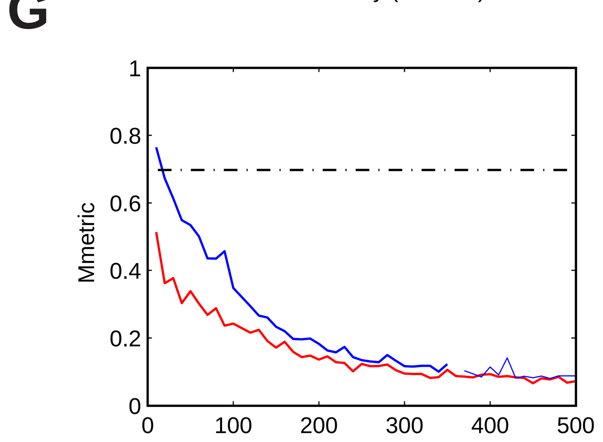
E



F



G



Mean Behavioral Performance

Percent Hit	87.79%
Inefficiency	6.5817
M-metric	0.6974

E. Percent hit. F. Path Inefficiency G. M-Metric. Dashed lines indicate average performance of primate in pole control over 719 trials, Red is unbiased random walk, blue is controller with radial angle uniformly drawn from a distribution $3\pi/2$ radians wide around the cursor-target vector.

Results

The performance of the random walk depends only its radial velocity. Generally for a faster radial velocity, the random walk is more likely to hit the target, however, the saturation and decay in plot E is due to the random walk overshooting the target. Also, as the inefficiency of path and M-metric are only defined for trials which go to completion, the regime at which a random walk performs best at these metrics is also the region at which the fewest targets were hit. Performance of the monkey controled trajectories is shown for comparison. The average radial velocity of these "pole controlled" movements was approximately 100 mm/sec. The biased and unbiased random walks perform similarly for both the path inefficiency and M-metrics. This is expected as these measure coordination directly.

Summary

We have shown that a random walk can be used to model the minimum performance expected from a controller. For each metric, the behaving primate outperformed the random walk. Even a metric as simple as percent targets hit can give a measure of the "intent" of a controller. However, more advanced criteria such as inefficiency of path or the M-metric, which measure coordiation, do not distinguish between the unbiased and target-biased random walks. Thus, these metrics can even be applied to tasks where percent target hit and other simple measures are not suitable.

References

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2. S. Zhai and P. Milgram. "Quantifying coordination and its application to evaluating 6 dof input devices." In *Proceedings of the SIGCHI conference on Human factors in computing systems*, Los Angeles, CA, 1998. ACM Press.
3. M. R. Masliah and P. Milgram. "Measuring the allocation of control in a 6 degree-of-freedom docking experiment." In *Proceedings of the SIGCHI conference on Human factors in computing systems*, The Hague, The Netherlands, 2000. ACM Press.

Acknowledgments

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