

Variability and Stability in Learning and Adaptation of a Rhythmic Ball Task

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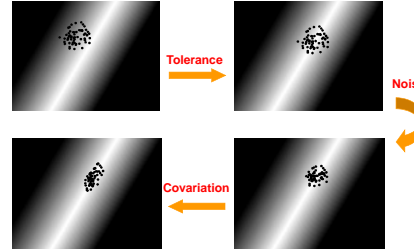
Introduction

It is well established that with practice performance improves with an exponential-like curve that asymptotically approaches a given yet still imperfect level. This "ceiling effect" has been attributed to the presence of irreducible neuromotor noise. One route for performance improvement is to reduce this noise to a minimal level (N-Cost). However, given the redundancy of the neuromotor system, two more routes exist that minimize the influence of noise: the second route is to channel the noise into directions that have little effect on the movement result by covariation (C-Cost). The third route is to identify strategies where noise matters less, i.e. where the system is insensitive or tolerant to errors (T-Cost) (Müller & Sternad, 2003, 2004; Cohen & Sternad, 2008).

To explore the changes in variability and noise with practice, we investigated ball bouncing, a simple motor task performed in a virtual reality environment where subjects rhythmically bounced a ball up to a target height. This task permits mathematical analysis that affords the quantification of T-, N-, and C-Cost. Further, this task has been shown to offer dynamic stability, with solutions that minimize the need for error corrections (Schaal et al., 1996; Sternad et al., 2001). Previous studies showed that human performers increasingly exploit this stability with practice.

The present study investigates how learning performance with stability is coupled with changes in variability and noise.

TNC-Cost Analysis: Decomposition of Variability

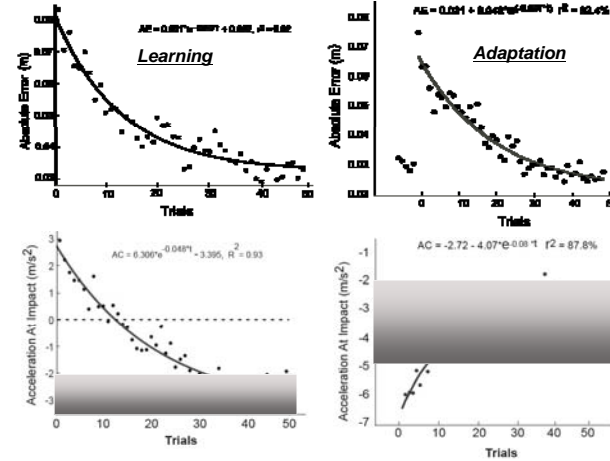


T-Cost: The difference in performance incurred after shifting the original data set to the optimal location in execution space without changing the distribution → cost due to non-optimal **tolerance**.

N-Cost: The difference in performance incurred after shrinking the original data set to the optimal "size" → cost due to non-optimal **noise**.

C-Cost: The difference in performance incurred after permuting the original data set to optimal covariation with the best result → cost due to non-optimal **covariation** of variables with respect to the manifold.

1. Results: Tuning Dynamic Stability



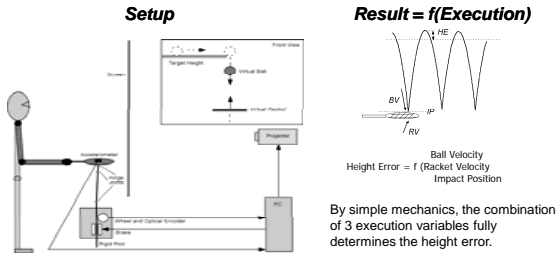
Performance, quantified by absolute height error within each trial, decreased exponentially, both during practice and adaptation.

Acceleration as the key indicator for dynamic stability shows exploitation of task stability. Previous studies demonstrated that for dynamic stability acceleration should be negative and in the range between -2 and -5 m/s².

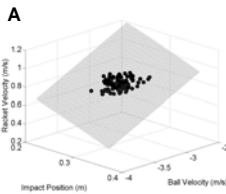
Methods

Protocol: 8 participants (4 male, 4 female). Day-1 (Learning): 48 normal trials; Day2 (Adaptation): 10 normal trials, followed by 48 trials with distorted execution space (explained below).

Instruction: Bounce the ball vertically to the target line and maintain a stable rhythmic bouncing pattern.

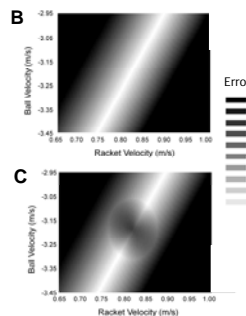


Execution Space

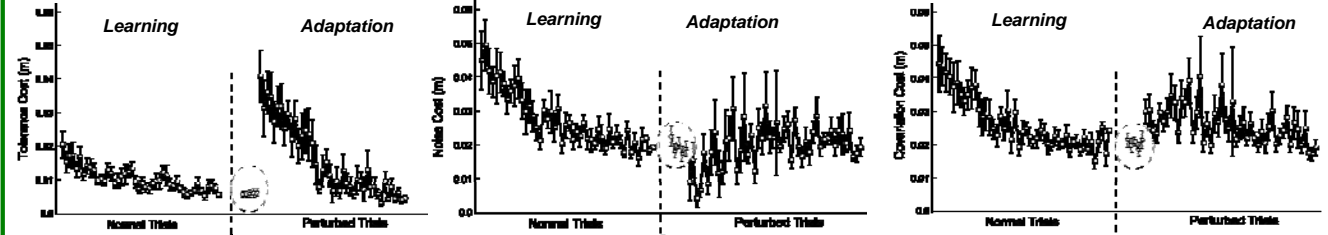


A: Solution manifold defined by HE=0.
B: Section of execution space taken at impact position = .30m.
C: Perturbation applied at a location centered at preferred solution of individual (after practice).

Distorted Execution Space



2. Results: Tolerance, Noise and Covariation

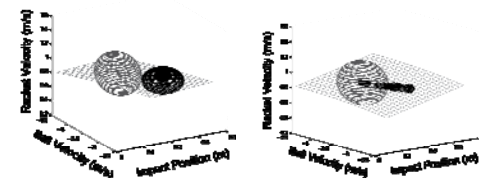


Subjects settled at their preferred locations and reduced T-Cost relatively fast during initial learning. Adapting and changing their initially preferred strategy, forced by perturbations, was much slower.

N-Cost was reduced with practice. Initial drop of N-Cost at beginning of adaptation is an artifact: as subjects' performance was perturbed, the performance improvement by shrinking procedure was confounded due to the migration of data. Indeed, after this initial change, N-Cost returned to baseline.

C-Cost is higher and its decrease is slower than T-Cost, indicating that it is more a fine-tuning process. C-Cost and N-Cost are of similar magnitude.

3. Results: Sensitivity to Variability



Variability ellipsoid before and after distortion. Note change in strategy includes: change of location without overlap into perturbed area; during adaptation variability is further reduced.

The ellipsoid is the perturbed region; each dot represents the average location during one trial.

Summary

- Consistent with previous results, humans exploit dynamical stability in rhythmic performance. Further, practice improves this aspect in performance. During adaptation this property is robustly re-established.
- With practice, humans find their preferred strategy in the redundant execution space (reduction of T-Cost). In addition, they fine tune their performance by reducing noise (N-Cost) and increase of covariation of execution variables (C-Cost). The latter two routes for improvements have a slower time scale. Compared to initial learning the search for new solutions takes longer.
- Following a perturbation of initial preferred strategy subjects establish a new strategy; variability of the new strategy shows no overlap with initial variability, reflecting sensitivity to their own variability.

References

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