Nonlinear Analyses of Movement Data using Cross Recurrence Measures

Michael J. Crites & Jamie C. Gorman

Texas Tech University

Introduction

- Human behavior unfolds on a moment-to-moment basis.
  - However, measures that are typically employed within psychological science merely provide the researcher with a snapshot of overall performance.
- We might collect behavioral data, for example, to provide a measure of total task time for performing a routine or novel task.
  - We can examine this task by analyzing task time; however, the underlying processes through which humans interact with the task to produce outcome performance are actually much richer.
- To develop a better understanding of the dynamic nature of human interaction, we employ methods allowing us to capture how behavior and cognition change over time (Gorman, Amazeen, & Cooke, 2010).
- Our objective is to highlight the added significance of nonlinear dynamical systems analysis for understanding how behavioral processes, even simple ones, unfold.
  - We demonstrate the added benefits of a dynamical method in a study wherein individuals performed a shoe-tying task.
- Specifically, we will highlight the significance of using nonlinear methods in combination with more conventional outcome performance analyses to understand how people performed a shoe-tying task.

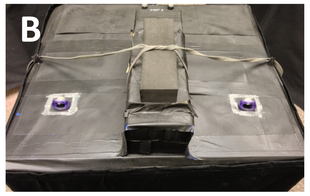
Method

- Individuals performed a shoe-tying task two ways:
  - *Bimanually* (i.e., individually, with their own two hands)
  - *Intermanually* (i.e., with another person, each handling a separate lace).

An example of the intermanual shoe-tying condition:

- Hence, participants performed the shoe-tying task in both a familiar, bimanual, and a novel, intermanual, coordination mode.
- During shoe-tying, we tracked participants' index in a motion capture volume that was located just above the starting/ending position (the "home keys") of participants' hands.
- Task Time was measured over multiple trials in each coordination mode as the time between the first hand entering the volume and the second (last) hand exiting the volume, in seconds.

Shoe-tying Task Environment

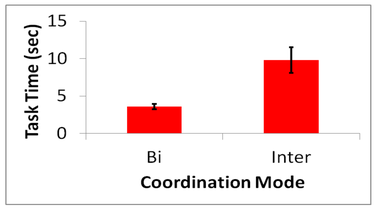


- **A** = Motion Capture Room
- **B** = The "Shoe"
- **C** = Participant wearing Ring with Reflective Marker

Traditional Analyses

- A statistical analysis was conducted on the more conventional measure (Task Time) to compare outcome performance when participants tied the shoe bimanually (Bi) vs. intermanually (Inter)

Traditional mean comparison of movement data using SPSS:

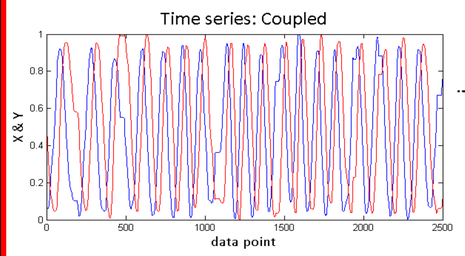


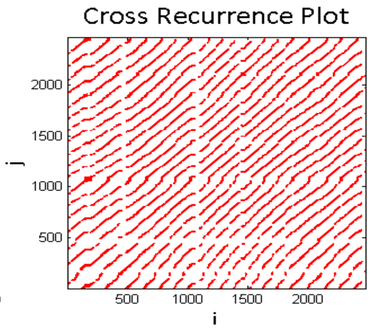
- Not surprisingly, a paired-samples *t*-test revealed that participants were significantly faster ($p < .05$) in the familiar, bimanual coordination mode than in the novel intermanual coordination mode ($d = 1.53$)

Cross Recurrence Quantification (CRQ)

- We know from the traditional analysis that, on average, bimanual performance was significantly faster than intermanual performance; from that analysis, we can only speculate on the moment-to-moment shoe-tying processes that underlie this difference.
- We further analyzed the motion capture data to examine the nonlinear dynamics that underlie the different performance outcomes of these two coordination modes.
- CRQ is a nonlinear method for assessing the coupling between any two dynamical systems (Shockley, Butwill, Zbilut & Webber, 2002).

Example CRQ of x- and y-axis data from tracing a circle:

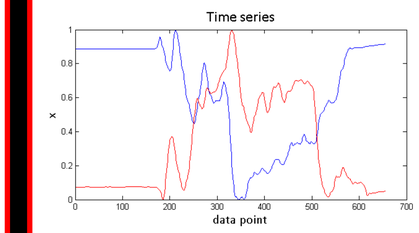


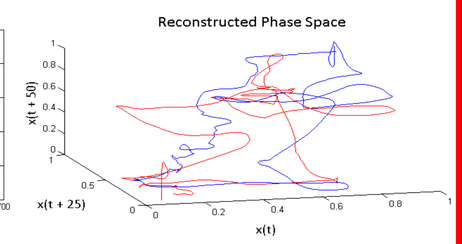


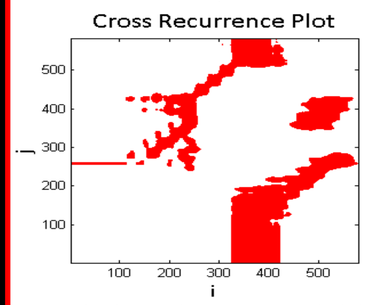
- For our purposes, CRQ provides measures of how strongly the two hands couple with each other during shoe-tying in the different coordination modes.
- Using this method, the movement time series for each hand was first unpacked into a proper dynamical space using phase-space reconstruction (PSR; Abarbanel & Gollub, 1996; Takens, 1981).
  - PSR parameters were obtained using the method of time delays and false nearest neighbors dimension selection.
- CRQ was then used to obtain measures of the recurring, time-dependent dynamic patterns across participants' hands in the shared dynamical space (Shockley, 2005).
  - The CRQ parameter radius was selected by examining an appropriate value of % recurrence (i.e., 5%).
- The CRQ measure MAXLINE was extracted from each trial to measure the stability of coupling between the hands.
  - Specifically, MAXLINE is the, "the longest shared trajectory and is a measure of stability of the shared activity." (Shockley, 2005).

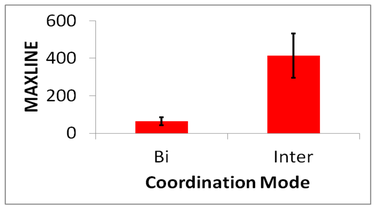
CRQ Results

- PSR and CRQ analysis were applied to the shoe-tying data with surprising results:









- A paired-samples *t*-test revealed that participants had significantly higher MAXLINE in the intermanual coordination compared to the bimanual mode ($p < .05$), such that the intermanual mode resulted in more stable coupling between the hands ($d = 1.20$).

Conclusions

- Whereas the traditional statistical analysis led to the relatively pedestrian finding that people are faster tying a shoe in the familiar bimanual coordination mode, the results of the nonlinear dynamical systems analysis revealed that, surprisingly, between-hands movement patterns were coupled with more stability than when tying with another person.
- Interestingly, this latter finding is consonant with previous research that examined the stability of relatively simple oscillatory movements as a function of movement frequency
  - For instance, Kelso (1995) observed that participants' movement stability during in-phase finger tapping varied as a function of speed, such that as movement frequency increased, coupling between the hands was lost, and the in-phase pattern became unstable.
- Taken together, the conventional outcome performance and nonlinear dynamical systems analyses of shoe-tying suggest that:
  - In past bimanual research, de-coupling between the hands occurs at higher movement speeds; hence, de-coupling between the hands may be an important feature of bimanual task speed.
  - The added significance of identifying underlying dynamical processes is that it may fundamentally alter how we come to view and explain the results of psychological research on conventional performance outcome variables.

References

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