Performance Monitoring and its Development – A Cognitive Systems Approach

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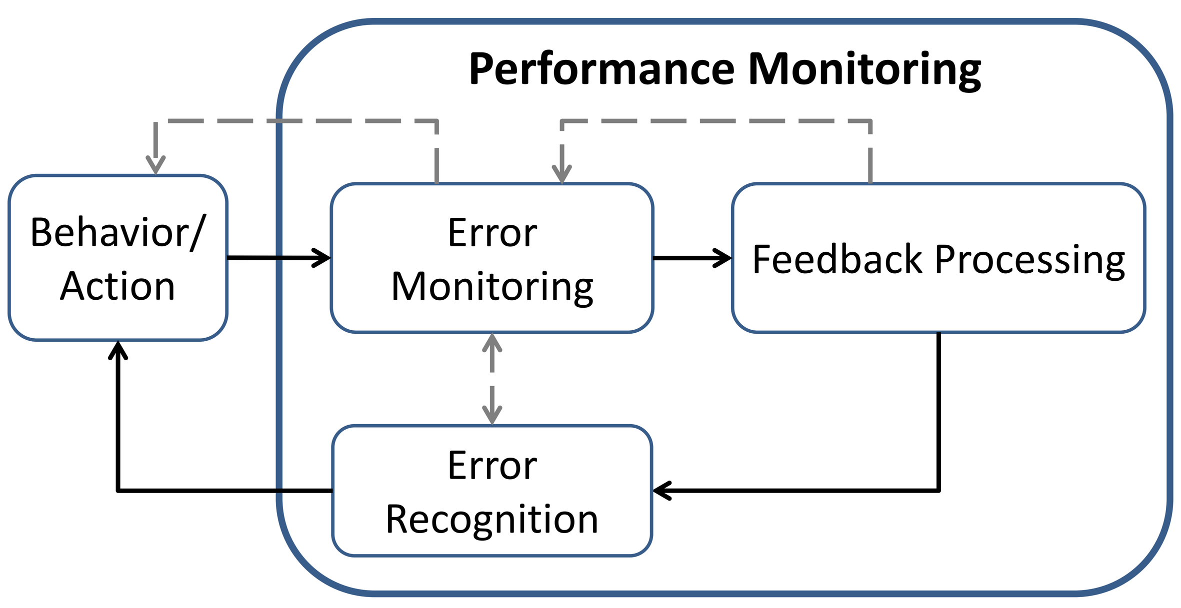
Background

Performance monitoring is comprised of several related but discrete processes: internal error monitoring, external feedback processing, and conscious error recognition. Together, these processes form a dynamic system that integrates externally and internally derived information to adjust behavior and facilitate learning.

Fig 1. Diagrammatic representation of the performance monitoring system and it's sub-components



Note: This model is a simplification of what is most likely a complex system of overlapping and parallelized processes. Solid lines represent a linear direction; dashed lines represent feedback loops.

Theoretically, the development of performance monitoring sees children transition from relying on external feedback to internal error models as they age, and this change is mirrored in relevant ERP indices. Despite the coordinated nature of this transition, most previous work does not consider how the development of these components may be interrelated. We recently observed developmental changes in the associations among unchanging performance monitoring ERP components, highlighting the importance of investigating performance monitoring as a system.

Structural equation modelling frameworks can be used to describe and predict the interactions between multiple components of a phenomenon viewed as a system, and also examine how the components and system evolve across time. Models within these frameworks are compatible with traditional EEG parameters, and can be readily computed.

Aims

Our aims are to use a systems-oriented framework to:

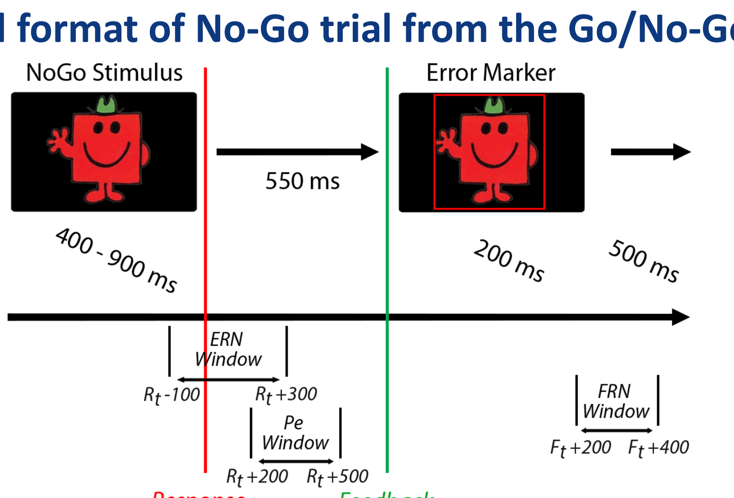
1. Build a within-wave model of performance monitoring, and examine how this changes with time.
2. Examine the lagged effects within and among performance monitoring processes across time.
3. Evaluate if the system or change within the system can be used to predict behavioral outcomes.

Participants

***Participants of the PATHS to Success Project** (Gatzke-Kopp et al., 2012)*

- 339 children (M_{age} = 6.05, SD_{age} = 0.38; 64.3% male) recruited from economically disadvantaged urban regions
- Assessed annually from kindergarten to 2nd grade.
- 70% African American, 9% Caucasian, 20% Hispanic, 1% Asian.

Figure 2: Trial format of No-Go trial from the Go/No-Go Task

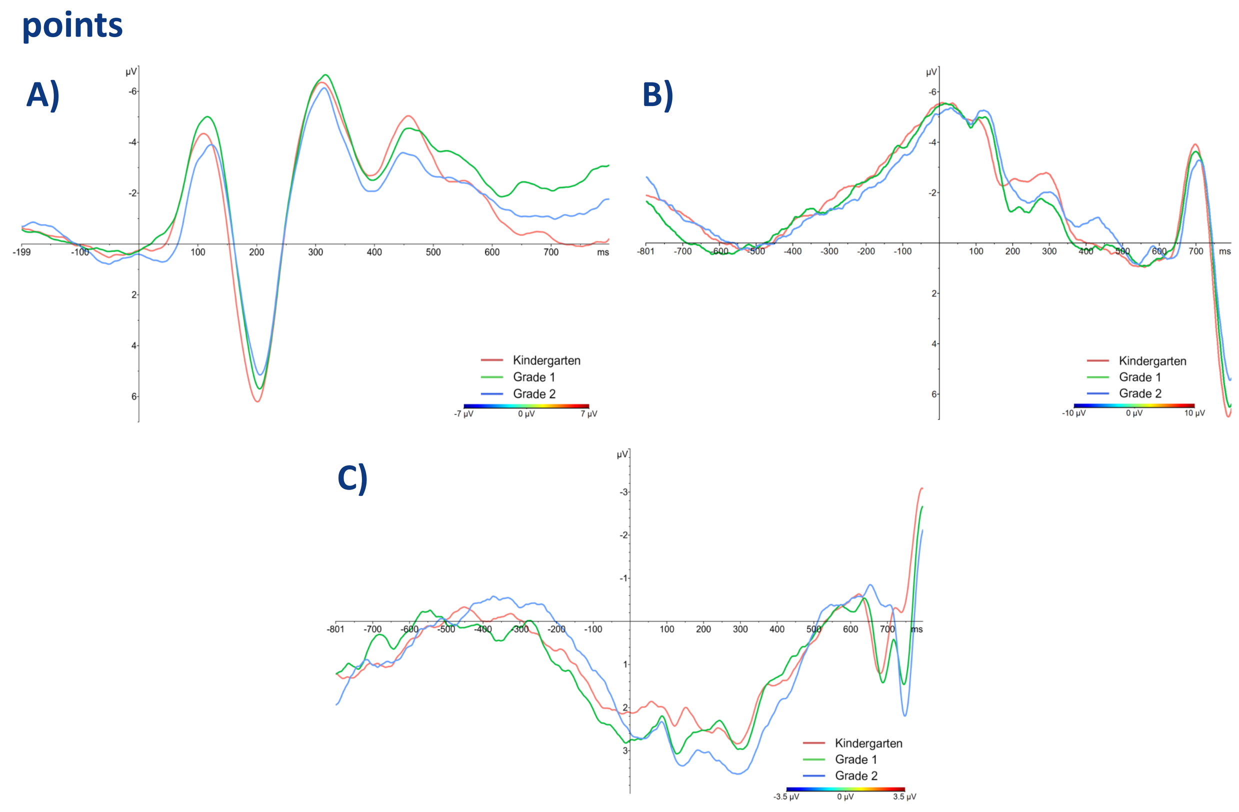


Note: Figure 2 presents the present No-Go trial format, and the corresponding post-response and post-feedback stimuli windows in which the ERN, FRN, and Pe were computed.

ERP Measurement

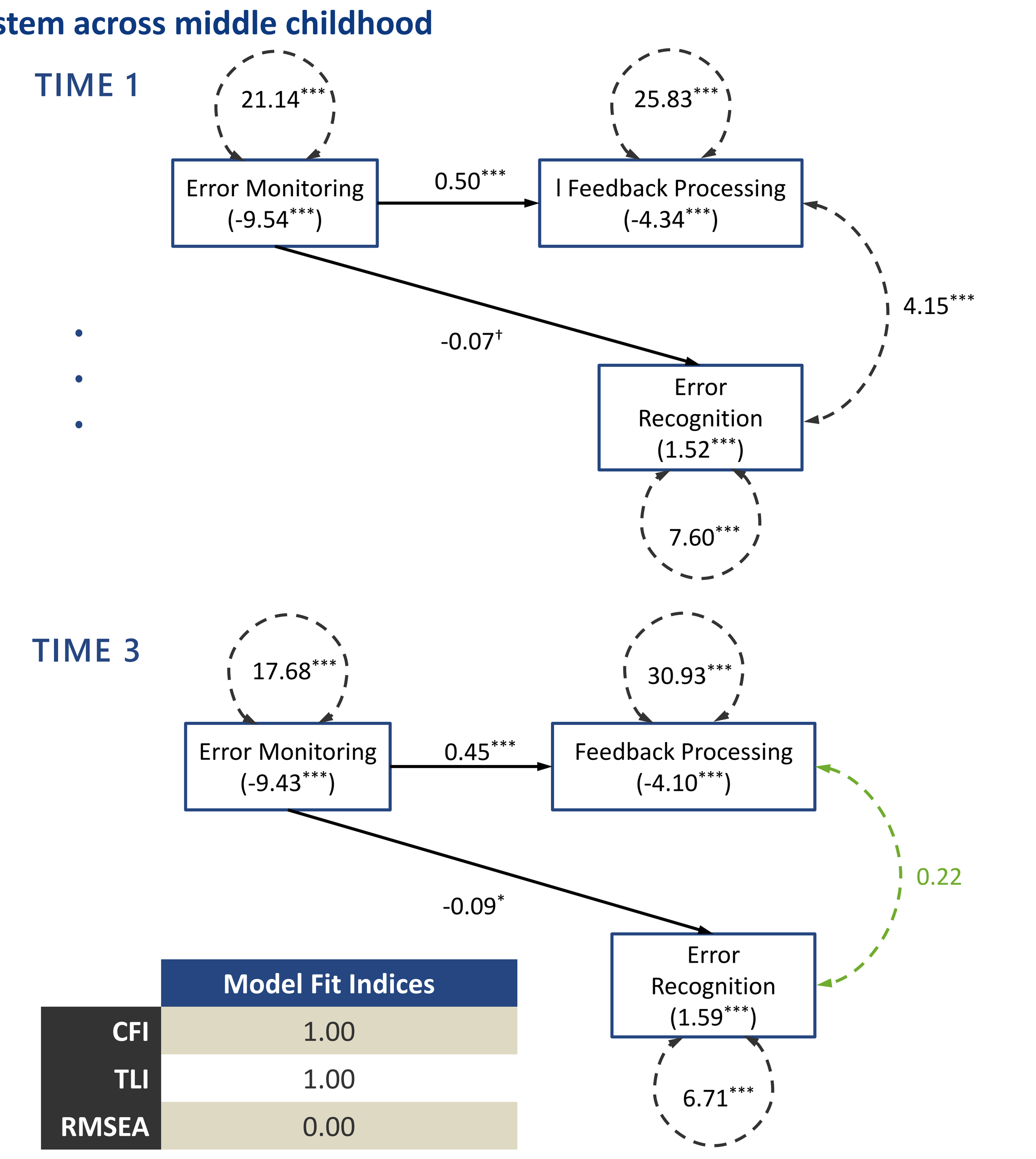
- Data recorded during an incentivized Go/No-Go task
- The FRN and ERN were derived at Fz as the most negative value computed using a sliding 20ms window (50% overlap) inside the 200-400ms post-feedback and -100-300ms post-response windows respectively.
- Pe was derived at Pz as the average amplitude across the 200–500 ms post-response window

Fig 2. Grand average FRN (a), ERN (b), and Pe (c) waveforms at all time points



Results

Model 1: Within-wave model examining the performance monitoring system across middle childhood



	Model Fit Indices
CFI	1.00
TLI	1.00
RMSEA	0.00

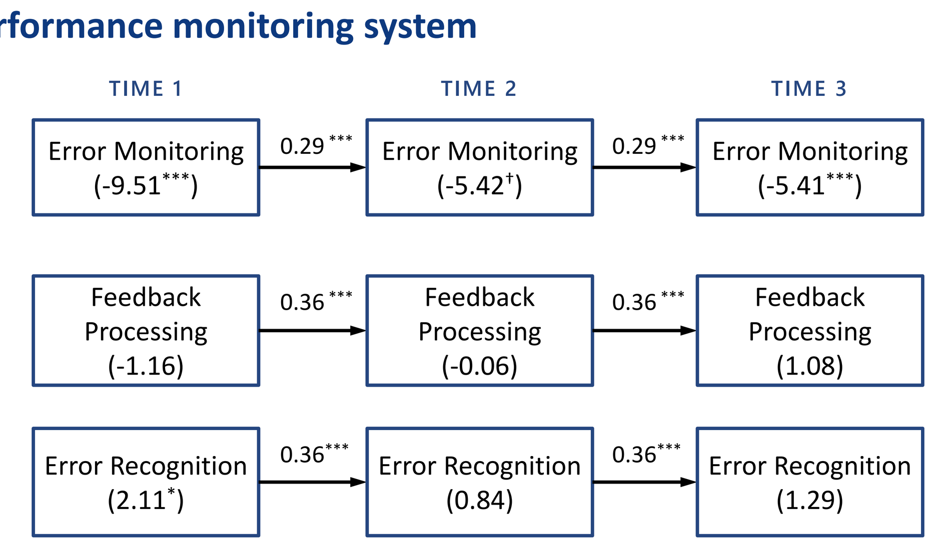
Note: A solid line represents a directional effect, while a dashed line represents a non-directional association. Green coloring indicates a significant change from the Time 1 model. The Time 2 model did not differ and so is not presented for clarity. †*p* < .1; **p* < .05; ****p* < .001

- Over time, there was a significant decline in the magnitude of the correlation between the FRN and Pe at Time 3 relative to T1;

  B_{T1} = 4.147 ± 0.928 ; B_{T3} = 0.223 ± 1.071

  - B_{diff} = 3.932, p = 0.006

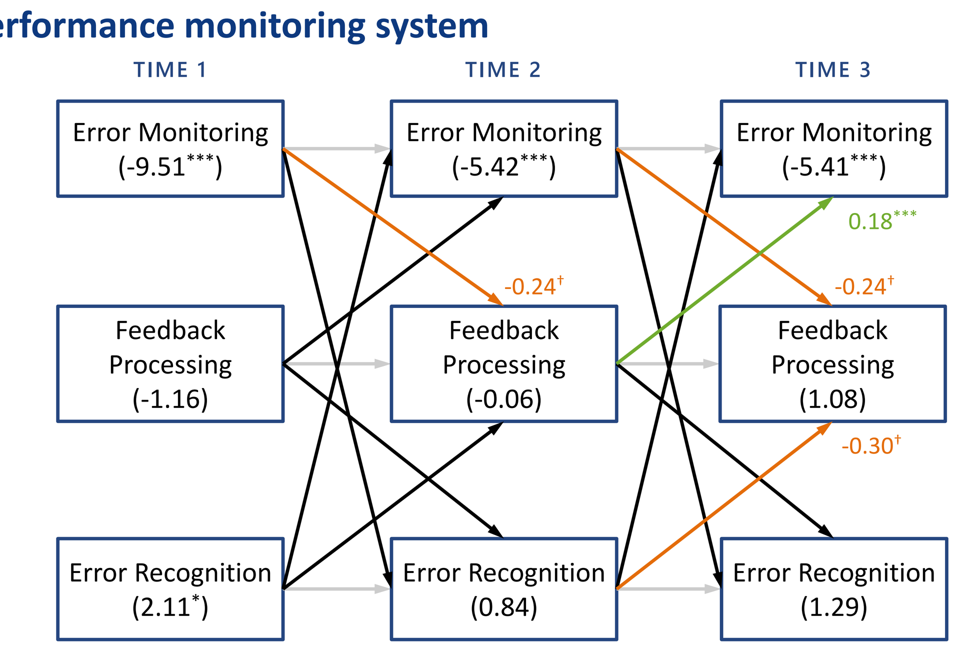
Model 2a: Cross-lagged phase model examining the effect of time on the performance monitoring system



Note: The within-wave paths, variances, and covariances as defined in the previous model were included in this model, they have been excluded from the plot for clarity. A solid line represents a directional effect. †*p* < .1; **p* < .05; ****p* < .001

- Within each process, the prior time-point significantly predicted the following time-point, i.e., Time 1 predicting Time 2
  - ***B's ≥ 0.29 ± 0.06; p's < 0.001***

Model 2b: Cross-lagged phase model examining the effect of time on the performance monitoring system



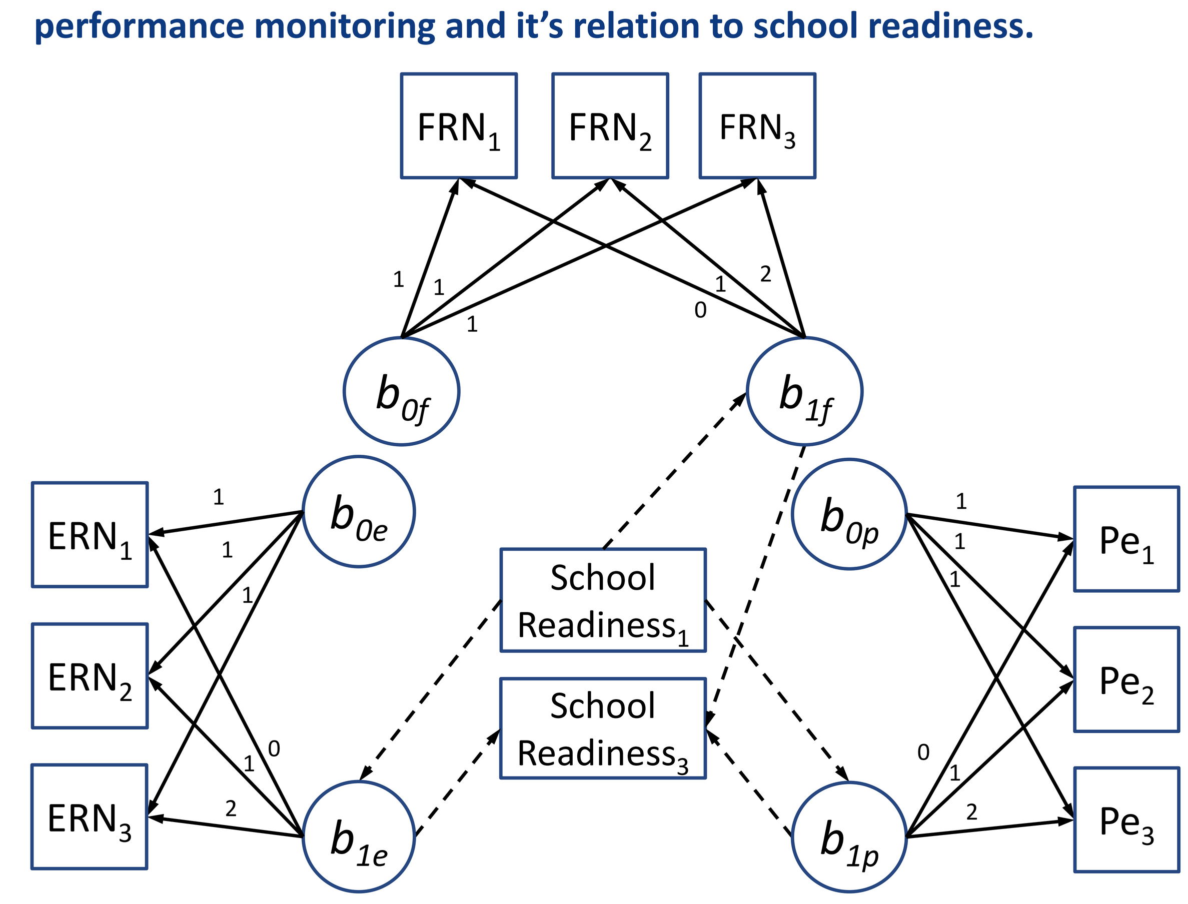
	CFI	TLI	RMSEA
Model Fit Index	0.96	0.91	0.05

Note: The within-wave paths, variances, and covariances as defined in the previous model were included in this model, they have been excluded from the plot for clarity. A solid line represents a directional effect; green coloring represents a significant effect; orange coloring represents a trending effect. †*p* < .1; **p* < .05; ****p* < .001

The effect of time across processes was such that:

- The FRN_{T2} significantly predicted the ERN_{T3}; ***B* = 0.18, p < 0.001**
- The $ERN_{T1/2}$ and Pe_{T2} trended towards predicting the $FRN_{T2/3}$; ***B* ≥ -0.24, p ≤ 0.07**

Model 3: Multivariate growth model predicting the development of performance monitoring and it's relation to school readiness.



	CFI	TLI	RMSEA
Model Fit Index	0.90	0.83	0.06

Note: Individual parameter variances (all constrained to be equal across time) and covariances (all but FRN ~ Pe constrained),and covariances among all intercept and slope factors (all freely estimated) are not shown for clarity. Solid lines represent latent factor loadings, while dashed lines represent directional predictive regressions.

- Individual ERP trajectories did not significantly predict school readiness at Time 3; *p's ≥ 0.355*
  - However, when combined the trajectory variables represent **83.7%** of the variance in school readiness.
- School Readiness at Time 1 did not predict ERP trajectory

Conclusions

System-oriented analyses may reveal results that are **not observable by individually examining** the **independent processes** of a system.

- Performance monitoring processes are linked and the nature of these links change over time.
  - Further, performance monitoring behavior at earlier timepoints predicts behavior at later time points
- Change in the performance monitoring system predicts school readiness, suggesting a role of this system in the development of self-regulatory behavior.
- Dynamical systems approaches and single-trial EEG analyses present further opportunity to concurrently examine within- and across-timepoint change.

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