Statistical modelling of development of executive function in early childhood

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Introduction

We investigate the development of executive control in young children:

- A group of 87 children were presented with a battery of executive function (Fig. 1) and false-belief tests at three time periods.
- We aim to examine the effects of task modifications (there are at least two different versions of each task) and explore interrelations between executive functions.

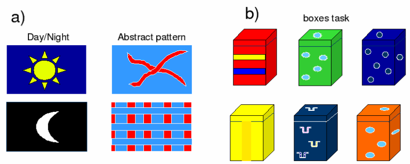

Figure 1: Materials for a) the day/night and abstract pattern tasks [these tests are designed to measure inhibitory control]; b) the boxes task [aimed to measure working memory]

Approach

- We assume the existence of an unobservable underlying cognitive ability, within each domain, for each child. We represent such unobservable ability by a latent variable.
- Conditional on the latent variable we use dynamic path analysis (Foren *et al.*, 2004) to model, jointly, the series of dependent outcomes within each domain.
- We extend the model to include the effect of time between test sessions.

Inhibitory control

First we restrict our attention to the executive function inhibitory control. Two individual paths of 16 binary outcome data (from day/night and abstract pattern tasks) at each time period were observed.

Model

We developed a dynamic logistic regression model with random intercepts. Fig. 2 shows the graphical representation of the fitted model.

Statistical inference

- Statistical inference for the regression parameters based on a conditional likelihood approach is suitable because it does not make distributional assumptions about the subject-specific effects; however
- regression coefficients of covariates that do not change within cluster are non-identifiable.
- Therefore we adopted a random effects model, but compared results with the conditional approach.

Results -inhibitory control data

Parameters	Model 1		Model 2	
	Estimate	SE	Estimate	SE
Age β	0.12	0.016		
Age bet $\beta_{\mathbf{B}}$			0.11	0.016
Age wit $\beta_{\mathbf{W}}$			0.18	0.037
Test δ_1	-1.083	0.098	-1.082	0.098
Groupδ_2	0.35	0.19	0.38	0.19
Prob η_1	2.05	0.075	2.05	0.075
Trial in η_2	-0.043	0.008	-0.043	0.008
T(2 vs. 1) γ_2	0.34	0.12	-0.031	0.23
T(3 vs. 1) γ_3	0.52	0.21	-0.23	0.44
Tst×gp δ_{12}	0.21	0.14	0.21	0.14

Table 1: MLE of regression parameters

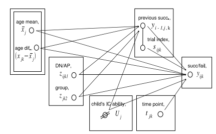

Figure 2: Dynamic logistic regression model with random intercepts

Working memory

We now consider the executive function working memory. Sequences of failures and successes until children retrieved 6 sweets were recorded at three time periods.

Model

Let $\boldsymbol{Z}_{jk} = (z_{ijk}, \ldots, z_{n_j jk})$ be fail/succ to retrieve a sweet in n_j trials at time period k. Let $S_{ijk} = 5 - \sum_{l=1}^{i} z_{ljk}$ be the no. of sweets that remain to be retrieved at trial i^{th} and time period k. We model $P_{ijk} = Pr(z_{ijk} = 1 | s_{ijk} = s)$, for $s = 1, \ldots, 5$ as

$$\text{logit}(P_{ijk}) = \alpha_s + \boldsymbol{X}'_{ijk}\boldsymbol{\beta}_k + \gamma_k + U_j$$

Statistical inference

The parameters of primary interest are the regression parameters and the subject-specific effects are regarded as nuisance parameters. The likelihood function is:

$$L(\alpha_s, \boldsymbol{\beta}; \boldsymbol{Z}_{jk}) = \prod_{jk} \int \prod_{s>1} \left\{ \left[\prod_{failures} (1 - P_{ijk}) \right] P_{ijk} \right\} f(U_i;\theta) \mathrm{d}U_j,$$

where $f(U_j;\theta)$ is the density function of the latent variable U_j

Results -working memory data

Parameters	Estimate	SE
Age β	0.057	0.018
Test (Scr vs. Sta) δ_1	-0.013	0.19
Group (2 vs. 1) δ_2	0.56	0.25
Time (2 vs. 1) γ_2	0.33	0.25
Time (3 vs. 1) γ_3	0.27	0.33
Test*group δ_{12}	-0.93	0.22
Time (2 vs. 1)*Test $\gamma_2\delta_1$	-0.75	0.28
Time (3 vs. 1)*Test $\gamma_3\delta_1$	-1.018	0.30

Table 2: MLE of regression parameters

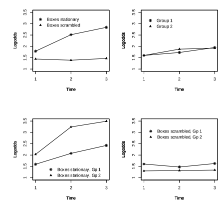

Figure 3: Plots of overall logodds

Relationships between executive functions

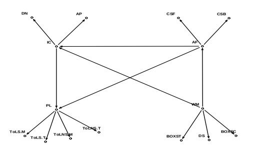

Figure 4:Inhibitory control and attentional flexibility are closely related skills that form the basis of planning and are underpinned by working memory.

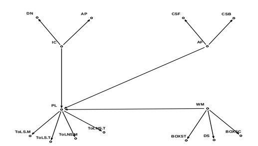

Figure 5: Planning is the superordinate executive skill requiring inhibitory control, attentional flexibility and working memory.

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