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Using finite mixture of GLMs to explore variability in children's flexibility in a task-switching paradigm

Bruno Dauvier[a], Nicolas Chevalier[b,*], Agnès Blaye[c]

[a] Centre PSYCLE, Aix-Marseille Université, Aix-en-Provence, France
[b] Institute of Cognitive Science, University of Colorado Boulder, Boulder, CO 80309-0345, United States
[c] Laboratoire de Psychologie Cognitive, CNRS and Aix-Marseille Université, Marseille, France

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ABSTRACT

The present study illustrates the usefulness of finite mixture of generalized linear models (GLMs) to examine variability in cognitive strategies during childhood. More precisely, it addresses this variability in set-shifting situations where task-goal updating is endogenously driven. In a task-switching paradigm 5–6-year-olds had to switch between color- and shape-matching rules as a function of a predetermined, predictable task sequence. A finite mixture of GLMs was fitted to explore individual differences in performance. The statistical model revealed five response profiles, defined by accuracy and response times. These response profiles likely correspond to different cognitive strategies with varying efficiency and differential relations to working memory capacity (assessed by backward digit span). These results illustrate the heuristic value of statistical modeling to reveal the behavioral and cognitive variability in the temporal dynamics of children's cognitive functioning.

Cognitive development has long been conceived as a stage-like progression toward increasing cognitive efficiency and maturity, as best illustrated by the large influence of Piaget's theory. According to stage theories, development consists of a universal progression through the same stages. At each stage, most or all children use the same processes and strategies. Yet, both within- and between-group variability in strategies is psychologically plausible. In most domains of development, recent research

* Corresponding author at: Institute of Cognitive Science, 345 UCB, University of Colorado Boulder, Boulder, CO 80309-0345, United States. Tel.: +1 303 492 6389; fax: +1 303 492 6389.
E-mail address: nicolas.chevalier@colorado.edu (N. Chevalier).

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has moved away from stage views and emphasized instead both intra- and inter-individual differences (Siegler, 1997). Exploring cognitive variability in any domain of cognitive development requires adequate methodological instruments. Here we argue that computational statistical modeling, more precisely finite mixture of autoregressive generalized linear models (GLMs; Lindsey, 1997), can provide new insights into cognitive variability, which we illustrate by examining the variability in the cognitive strategies that preschoolers use to update goal representations in a set-shifting task that assesses executive control.

Classical statistical frameworks (e.g., analysis of variance) generally are characterized by a substantial gap between the theoretical representations of the targeted psychological processes and the statistical hypotheses that are actually tested because these frameworks are almost always based on aggregated data at the group level while psychological processes occurred at the individual level. In contrast, statistical modeling bridges this gap by estimating parameters at the individual level; these parameters directly reflect cognitive processes and thus can be interpreted more straightforwardly in terms of cognitive functioning. GLMs offer a wide range of very flexible tools to investigate psychological processes. They also provide the opportunity to address several theoretical issues within a single analysis, reducing the risk of hidden effects due to data aggregation. For instance, in our study this type of modeling allowed us to test our main theoretical questions within a single model using one set of parameters for each question, whereas several distinct analyses would have been necessary using a classical statistical framework.

Statistical modeling offers the possibility of exploring individual differences in depth. Models based on latent classes identify groups based on their response profiles. When one examines variability in cognitive processes or strategies, expected individual differences are more qualitative than quantitative. In such cases, individual response profiles are not ordered along a continuum. Because latent class models handle a priori unknown qualitative differences among groups of individuals, they are especially well-suited to explore individual differences. Models that combine the flexibility of GLMs with the possibility of revealing latent classes are known in the statistical modeling literature as finite mixture of generalized linear models (Grün & Leisch, 2008) or variance components GLM (Aitkin, 1999). Their main principle is that the relations that exist among multiple variables in a dataset often are more accurately characterized by multiple regression models with different parameter values, fitted to different latent subgroups of individuals, relative to a single set of parameter values for the entire sample. In addition, these regression models can be built to reflect the temporal dynamics of cognitive processes (e.g., with age, across experimental sessions or even across trials within a session), which is done through an autoregressive term that uses the current state of the cognitive system as an explanatory variable to predict the next state of the system (Aitkin & Alfo, 2003). This methodology is a powerful tool to study behavioral and cognitive variability both between and within subjects. Here we illustrate the heuristic value of such statistical models in the context of children's executive control and, more specifically, goal updating strategies in set-shifting situations.

Executive control refers to the intentional and goal-directed regulation of one's own thoughts and actions. It allows one to orient attention toward goal-relevant information and appropriate behaviors. Executive control is required, and can be exerted, only if one has a specific goal to achieve. For instance, children can orient their attention to the information relevant to solve an arithmetic problem only if they intend to solve this particular problem. Forming a representation of the relevant task, that is, deciding about the relevant task goal, is challenging for preschoolers especially when tasks constantly change, as is the case in task-switching situations, such as the Advanced Dimensional Change Card Sort (Advanced DCCS), where children have to switch between matching a bidimensional stimulus with response options by color or shape as a function of task cues (e.g., a star beside the stimulus signals that color is relevant while a square means shape is relevant; Zelazo, 2006). Consistently, recent evidence suggests that set-shifting development is largely driven by improvement in goal representation (Chevalier & Blaye, 2009; Marcovitch, Boseovski, & Knapp, 2007; Morton & Munakata, 2002; Snyder & Munakata, 2010).

Thus far, research has begun to uncover the processes underlying goal representation in situations in which children are provided with some environmental information, such as task cues (Blaye & Chevalier, 2011; Chevalier & Blaye, 2009; Chevalier, Wiebe, Huber, & Espy, 2011), response feedback (Chevalier, Dauvier, & Blaye, 2009), or common stimulus features (Snyder & Munakata, 2010). How do