*High Ability Studies*
*Vol. 18, No. 1, June 2007, pp. 89–92*





COMMENTARY ON ERICSSON ET AL.

# Cognitive functions of the cerebellum explain how Ericsson's deliberate practice produces giftedness

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A critical issue for Ericsson *et al.*'s proposal is the development of a fully adequate description of neurophysiological substrates for deliberate practice. Ericsson *et al.* do provide two substantial subsections on biological substrates—namely, their subsections, 'Acquisition of superior power, control, and speed of motor activities' and 'Improvement in the selection of actions in representative situations'. However, as it stands, these discussions do not adequately explain the remarkableness of giftedness.

To get at the details of the subtle effects of deliberate practice, Hesheng Liu[1] and I recently proposed a thoroughgoing neurophysiological explanation of the child prodigy (Vandervert & Liu, in press). Our explanation is based upon the *collaboration* of working memory and cognitive functions of the cerebellum (Ito, 1997, 2005; Vandervert, 2003a, b; Vandervert *et al.*, 2007). In our approach all *repetitive* working memory processes taking place in the cerebral cortex (e.g., in deliberate practice) are *adaptively modeled* in the cerebellum (see Ito, 1997, 2005; Chein *et al.*, 2003; Vandervert *et al.*, 2007). When the resulting cerebellar control models are fed back to working memory areas of the cortex, the thought processes of working memory become faster, higher in attentional control, and more appropriately and optimally timed (Akshoomoff *et al.*, 1997; Ito, 1997, 2005; Ivry, 1997).

The above newer role of the 'cognitive cerebellum' (see Schmahmann, 1997; Ramnani, 2006) offers needed detailed support for Ericsson *et al.*'s proposal. In addition to the cerebellum constructing adaptive models of mental activity occurring in working memory, it has been convincingly argued that the cerebellum does this in the form of multi-pairs of models that constitute complex *modular* architectures for mental processes that when fed to working memory functions in the cerebral cortex act to *facilitate the development of new, higher levels of performance* (Haruno *et al.*, 1999; Wolpert *et al.*, 2003). This process comes about through the combination of learned

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ISSN 1359-8139 (print)/ISSN 1469-834X (online)/07/010089-4

DOI: 10.1080/13598130701350940

'forward' and 'controller' pairs of cerebellar models. *Forward* cerebellar models are anticipatory/exploratory controls for movement and thought, and *controller* models are automatic controllers that are learned through the repetition of successful forward models. The resulting cerebellar control architecture has been termed Hierarchical Modular Selection and Identification for Control (HMOSAIC) (see Imamizu *et al.*, 2003; Wolpert *et al.*, 2003; see also Leiner *et al.*, 1991; Leiner & Leiner, 1997, for modular specificity between the cerebellum and prefrontal areas of the cerebral cortex.) New, hierarchically-arranged *levels* of the cerebellar control architecture (HMOSAIC) develop *as practice is extended over time*. These levels are direct explanatory counterparts to the stages Ericsson *et al.* describe in their Figure 1.



## Cerebellum-mediated stages of deliberate practice

Japan Prize laureate Masao Ito (1993, 1997, 2005) has long made the case that movement and thought are, in terms of cerebrocerebellar system neurology, 'identical' control objects. Thus, in terms of *neural control*, hands, feet, computer keyboards, for example, and all thoughts are equivalent 'control objects'. In describing how pairs of forward and controller cerebellar models work together, Ito (2005) commented on how advances in both motor and mental control would take place at an unconscious level:

> If the forward and inverse [controller] model controls are combined, an interesting possibility emerges [after much practice] that the cerebellum conducts the entire process of thinking … which will not come up to the level of consciousness. This may explain our daily experience that, after repeated trials of learning, a correct answer [or a correct movement] pops out readily without a conscious effort. (Ito, 2005, p. 102)

Because forward models may be uniquely combined with other forward models in HMOSAIC, or variant forward models may be composed from the possibilities of movement or thought spaces already learned (Haruno *et al.*, 1999, 2001; Wolpert *et al.*, 2003), the above process Ito describes would also advance behavioral and mental capabilities to higher, goal-directed levels.

Hesheng Liu and I believe that this process takes place countless times during a developmentally initiated version of deliberate practice as the individual transitions to the development of new, more accomplished levels of the HMOSAIC architecture (Vandervert & Liu, in press). In this regard, we argued how the development of HMOSAIC can be accelerated along modular lines through high attentional control starting in early infancy and thus account for the child prodigy. It is important to note here that the cerebellar modules of the deliberate practice architecture include thought, movement, attentional and emotional components (see Schmahmann, 2004).

In regard to Ito's above comment concerning 'cerebellum-mediated thinking', what 'pops out' due to cerebellar modeling is *either* the well-learned solution to a problem (as Ito suggests) or it is the next silently emerging instance, level or stage of gifted performance. If there is a 'silent' or 'mysterious' mechanism behind the remarkableness of giftedness, I believe it lies here in the 'quietude' of cerebellar modeling within HMOSAIC that occurs in small forward/controller modeling increments during Ericsson *et al.*'s deliberate practice.

## Note

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