
COMMENTARY

Can a Neural System Geared to Bring About Rapid, Predictive, and Efficient Function Explain Creativity?

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ABSTRACT: Vandervert, Schimpf, and Liu (this issue) have presented a cerebellar model of creativity in the featured article by relating their ideas to processes of working memory in relation to the cerebellum as well as by generalizing the motor control role of the cerebellum to extend to non-motor facets of cognition. In the present article, I discuss the weaknesses of their approach at different levels, ranging from the inadequate definition of the construct of study and a lack of specificity of their claims, to the counterintuitive underlying rationale of their approach, and the inadequate evidence provided to cement their ideas. I end by briefly outlining what would be necessary to propound an account of creativity that is uniquely attributable to cerebellum function.

In the featured article titled “How Working Memory and the Cerebellum Collaborate to Produce Creativity and Innovation” by Vandervert, Schimpf and Liu (this issue), working memory was conceptualized as a key facet of cerebellar function, which was, in turn, deemed to be a vital building block for creativity. As evidence for their claims, parallels were drawn between introspective information from Albert Einstein on his own streams of thought and the processing features of their model. The authors fittingly highlighted the function of multiple factors such as stimulus-independent thought and imagery and working memory in relation to neural dynamics in understanding creativity. Unfortunately, what is lacking are clear grounds that support the claim of the primacy of the role of the cerebellum in these processes and in creativity. The weak-

nesses of their approach are detailed in the themed sections that follow.

Definition

The authors put forward a novel theory to account for creativity and innovation, with particular reference to mathematical discovery, but they do not define their conception of creativity or outline factors that they believe are critical to their model of creative function. Does their theory hold true only for mathematical creativity? What factors make mathematical creativity separable from artistic or even other types of scientific creativity? Clarity at the level of definitions is necessary not only because delimiting claims helps make hypotheses more concrete but also because it is only then possible to clearly assess the power and fitness of the model they propose.

Empirical Support

The authors link diverse research domains together in presenting their model, but even if there could be some degree of indirect linkage between the different concepts, there are sizeable gaps that they leap over

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without presenting any caveats for the same. There is no indirect or direct evidence cited that implicates a special link between cerebellar function and creativity, for instance. They also do not present any evidence for the link between working memory and creativity despite the fact that this has been the subject of both theoretical (Dietrich, 2004) and experimental (Lavric, Forstmeier, & Rippon, 2000) efforts, which, however, do not link up working memory and creative processes in quite the same manner as proposed in the featured article. How working memory and the Modular Selection and Identification for Control (MOSAIC) model or the hierarchical MOSAIC model (e.g., Haruno, Wolpert, & Kawato; 2001; Wolpert, Doya, & Kawato, 2003; Wolpert & Flanagan, 2001) are related is yet another association that, although presumed, is not entirely clear. Even if all of these hypothetical connections were to be taken for granted, one still loses sight of what exactly is being proposed in the model because arguments broached regarding why the bridges the authors make are the most plausible ones are not elucidated in any detail.

Specificity

The role of the cerebellum in cognitive operations has been understated in the past. Extensive proof of the involvement of the cerebellum in a wide range of processes, as has been attested by functional imaging studies (for a review, see Cabeza & Nyberg, 2000), suggests that it is no longer possible to consider the cerebellum as a purely movement-related structure. However, what is yet to be clearly determined is the specificity of the role of the cerebellum in different facets of cognition. In the case of working memory, one of the primary focal points of the featured article, there is now abundant literature on this theme, although the details concerning the precise function of the cerebellum in working memory is still debatable. The authors are rather vague about the function of the cerebellum in working memory, sometimes aligning it with the central executive and sometimes with the visuospatial sketchpad. In fact, the cerebellum has been chiefly linked to articulatory rehearsal processes in working memory, and recent evidence suggests that it could also play a role at the phonological encoding stage (e.g., Ravizza et al., 2006).

With regard to the central executive in working memory which has been the subject of extensive research, a review of functional imaging studies by Collette and Van der Linden (2002) highlighted the need to classify the different functions of the central executive into component processes such as updating, shifting, inhibition, and dual-task coordination. Consistent cerebellar activity was associated only with the updating function (similar to its function in the motor system) in the central executive, which was also equally associated with activation in several other brain regions in the frontal, cingulate and parietal cortices. So the complexities of working memory function cannot be generally aligned only with the cerebellum any more than it can be aligned only with frontal lobe function, as has been the case in the past.

The lack of specification of the role played by the cerebellum in as complex a process as working memory and the disregard of the contributions of several other highly pertinent areas of the brain poses considerable problems for the model proposed by Vanderwert and his colleagues. There can scarcely be any doubt that understanding the dynamics of processes in working memory is fundamental to understanding creative cognition. However, accurate assessment of the type of cerebellar contribution in these functions requires a clear definition of what it is that cerebellar function, as distinct from other brain functions, entails.

Overgeneralization and Omission

The lack of specificity goes hand in hand with problems related to overgeneralization with reference to cerebellar function and omission with reference to other factors that vitally contribute to the larger picture. The authors advocate a link between creativity and cerebellar function but neglect to mention that creative function is classically associated with frontal lobe and temporal lobe function (e.g., Carlsson, Wendt, & Risberg, 2000; Folley & Park, 2005; Jung-Beeman et al., 2004; Lavric et al., 2000; Miller et al., 1998; Molle et al., 1996). In one of their footnotes, they try to account for the finding by Jung-Beeman and his colleagues (2004), of greater activation in the right superior temporal gyrus when generating insight relative to noninsight solutions, by attributing the recorded activation solely to the signal of the actual insight after all the processing had taken place. This is debatable of

course, but it would have been interesting and helpful to have more feedback of this nature regarding the authors' views on alternative findings in the literature.

They also referred to psychological evidence that demonstrated that although stimulus-independent thoughts are, by definition, unrelated to direct sensory input, the production of stimulus-independent thoughts was found to depend on central executive resources in working memory (Teasdale et al., 1995). Again, how this refers to the cerebellum is unclear. For instance, in an effort to determine which of the wide range of regions that have been reliably recruited, both during rest as well as in higher cognitive tasks, that underlie stimulus-independent thought, Christoff, Ream, and Gabrieli (2004) carried out a functional magnetic resonance imaging (fMRI) study on spontaneous thought generation. Robust activation was seen in the temporopolar cortex and the parahippocampus (suggestive of a central role for long-term memory processes), with smaller contributions from the rostrolateral prefrontal, visual, and parietal cortices but not the cerebellum.

This kind of nonspecificity is also true in their allusions to imagery. The extensive review by Cabeza and Nyberg (2000) on 275 positive emission tomography and fMRI studies revealed that the activation of the cerebellum during nonmotor imagery tasks is rare. They summarized their review on studies on imagery with the revelation that visual mental imagery is mainly related to activity in the visual association cortex with different areas being recruited according to task demands. The fact that Vanderwert and his coauthors gloss over such details and generalize the function of the cerebellum to include a wide range of such processes is questionable enough, but neglecting to take into account the importance of other cortical areas in these functions is problematic for their model.

Rationale

The authors use inferences based on the MOSAIC model and the higher level hierarchical MOSAIC model of motor control to substantiate most of their ideas. The MOSAIC model (Haruno et al., 2001; Wolpert et al., 2003; Wolpert & Flanagan, 2001) is a highly influential paradigm that established the importance of internal models that refer to neural mechanisms that simulate select aspects of planning, control,

and learning in the sensorimotor circuit to enable optimal and efficient motor control. Although inverse internal models can estimate the required feed forward motor commands from the desired trajectory information, forward internal models can predict sensory consequences of elicited motor commands from efference copies of the same. Because of the ever-changing dynamics of the environment and our own bodies, forward models must be constantly updated through experience so as to have highly accurate predictive power, and there is evidence that supports the role of the cerebellum in the prediction of the sensory consequences of action (e.g., Blakemore, Frith, & Wolpert, 2001).

Even if one were to accept that these models of motor control can be generalized to the cognitive domain, it is not apparent how such models would enable creative and innovative thinking. The cerebellum is geared toward bringing about rapid and efficient responses on the basis of past experience. Prediction is thus a hallmark of cerebellar function. However, innovativeness, by definition, is the ability to be original, which is essentially the opposite of predictability. So although the cerebellum is involved in dynamically updating motor plans (or cognitive or mental plans in this case) in response to novel scenarios, this has little, if anything, to do with the actual generation of unique and innovative responses or ideas. In fact, one could presumably argue that the opposite is true—that a system involved in generating plans that are by nature predictive and pose the least likelihood for error, inevitably biases the system to be uncreative and low in innovativeness because the system, by its very nature, does not allow for uniqueness to be propagated.

There is a large body of evidence that links cognitive biases arising as a result of mild insufficiencies in different aspects of cognitive processing efficiency to enhanced creative ability. Personality-based studies, for instance, have found an association between creative thinking and schizotypy, which is a personality construct reflecting nondysfunctional personality traits that corresponds to diminished levels of schizophrenic symptoms (e.g., Folley & Park, 2005; Karimi, Windmann, Güntürkün, & Abraham, in press; Mohr, Graves, Gianotti, Pizzagalli, & Brugger, 2001; Schuldberg, 2001). Inadequate cognitive and motor inhibition has been consistently associated with schizotypy (e.g., O'Driscoll, Lenzenweger, & Holzman, 1998; Lubow, & De la Casa, 2002; Holahan & O'Driscoll, 2005) as well as on other fac-

ets of executive function such as working memory (e.g., Lenzenweger & Gold, 2000; Park & McTigue, 1997) and set shifting (e.g., Gooding, Kwapil, & Tallent, 1999). Weaknesses at the level of inhibition have been posited to allow for enhanced potential for creative ability as the inability to screen out irrelevant stimuli could contribute to original thinking by allowing for novel combinations and associations between remotely associated conceptual elements in one's thought stream. Carson, Peterson, and Higgins (2003) reported evidence in support of this association by linking decreased latent inhibition and increased creative achievement in high-IQ individuals.

Presumably, the model by Vanderwert and his colleagues was designed to explain qualitatively different aspects of creativity. But because they are not specific about what they mean by creative function, this is impossible to determine. How the concept of efficiency of the cerebellar system bears on innovation in their proposal should ideally outline how their model would lead to results that are distinct from the kinds of findings presented above that are, at least on the face of it, counterarguments to their ideas.

In addition, there is also the need to verify the concept of timing as a critical variable in their model of innovation as this variable is also unclear in how it relates to creativity. The authors stated that "the cerebellum provides a fast computational system for the timing, sequencing, and modeling aimed at the rapid manipulation of both motor and cognitive processes." Precise event timing has for long been characterized as a key feature of cerebellar function (e.g., Ivry, Spencer, Zelaznik, & Diedrichsen, 2002). But what would make such rapid processing advantageous for creative thinking?

A series of experiments by Dijksterhuis and Meurs (2006), for instance, found evidence to the contrary in that they demonstrated that a few minutes of distraction aided creativity on an idea-generation task. After being given instructions for the creativity task, one group of participants were required to respond immediately, another group were allowed to deliberate on the task for 2 min before responding, and a third group were to work on another unrelated cognitively demanding task—such as a working memory task—before responding. The latter distracted group generated more original ideas than did the other groups across all experiments, which the authors attributed to access to

normally more divergent and low-relevance concepts in unconscious thought. This kind of finding does not support the importance of rapid processing in the ability to be creative. So again, it is important that the authors clearly state what specific aspects of creativity would be aided by such rapid integration processes in relation to event timing that are attributable to the cerebellar function.

Empirical Basis

The evidence the authors cite as support for their ideas are introspective accounts of Albert Einstein on his insights into his own thinking processes. Introspection has very limited use as evidence for any cognitive process because one's own experience of mental phenomena tells us very little about the workings of the actual cognitive operations underlying such phenomena. So if introspection is to be used as evidence, it should be in conjunction with real empirical support. Considering that there are a multitude of studies on creativity in relation to almost any other variable, it is surprising that the authors did not cite a single empirical study as relevant to their claims. Even if linking up their ideas to empirical results would only amount to an indirect connection, it would have still constituted a far superior and stronger approach relative to the purely introspective accounts they used.

Moreover, the introspective accounts they referred to could have just as easily been attributed to involve other areas of the brain and not exclusively the cerebellum. The prefrontal cortex, for instance, is involved in many aspects of higher order cognition and could therefore entail a justifiably crucial part in voluntary combinatorial play as regions in this structure have been shown to be consistently involved in manipulation of information in working memory (Collette & Van der Linden, 2002). With regard to linking problem elements with potential solution elements, semantic memory association networks are obviously involved, which means that a significant role for the temporal cortex and inferior frontal gyrus—areas involved in semantic selection and retrieval (Thompson-Schill, 2003)—cannot be disregarded. So the evidence the authors presented as support for their ideas could just as easily support alternative accounts.

Conclusion

How a neural system that is evolved to bring about fast, efficient, and predictive function can also alternatively give rise to unique or original responses that are necessarily low in predictability remains an unconvincing idea in its present form. It is hence vital that the authors of the featured article clearly specify what facets of the multidimensional construct of creativity they aim to explain. As they relate their ideas to cerebellar function, this would necessarily mean that they need to identify which aspects of creativity are critically affected by the impact of dynamic updating of the predictability, timing, and efficiency of neural processes. One way to ensure the reliability of their approach would be to contrast patients with cerebellum damage to other neurological populations and nonneurological groups on tasks that they believe are designed to tap elements of creative thinking that are especially regulated by cerebellar function. As timing is a key variable here, their approach would also benefit from using event-related electrophysiological paradigms that are superior in temporal resolution.

References

Blakemore, S. J., Frith, C. D., & Wolpert, D. M. (2001). The cerebellum is involved in predicting the sensory consequences of action. *Neuroreport*, *12*, 1879–1884.

Cabeza, R., & Nyberg, L. (2000). Imaging cognition II: An empirical review of 275 PET and fMRI studies. *Journal of Cognitive Neuroscience*, *12*, 1–47.

Carlsson, I., Wendt, P. E., & Risberg, J. (2000). On the neurobiology of creativity. Differences in frontal activity between high and low creative subjects. *Neuropsychologia*, *38*, 873–885.

Carson, S. H., Peterson, J. B., & Higgins, D. M. (2003). Decreased latent inhibition is associated with increased creative achievement in high-functioning individuals. *Journal of Personality and Social Psychology*, *85*, 499–506.

Christoff, K., Ream, J. M., & Gabrieli, J. D. (2004). Neural basis of spontaneous thought processes. *Cortex*, *40*, 623–630.

Collette, F., & Van der Linden, M. (2002). Brain imaging of the central executive component of working memory. *Neuroscience and Biobehavioral Reviews*, *26*, 105–125.

Dietrich, A. (2004). The cognitive neuroscience of creativity. *Psychonomic Bulletin & Review*, *11*, 1011–1026.

Dijksterhuis, A., & Meurs, T. (2006). Where creativity resides: The generative power of unconscious thought. *Consciousness and Cognition*, *15*, 135–146.

Folley, B. S., & Park, S. (2005). Verbal creativity and schizotypal personality in relation to prefrontal hemispheric laterality: A behavioral and near-infrared optical imaging study. *Schizophrenia Research*, *80*, 271–282.

Gooding, D. C., Kwapil, T. R., & Tallent, K. A. (1999). Wisconsin Card Sorting Test deficits in schizotypic individuals. *Schizophrenia Research*, *40*, 201–209.

Haruno, M., Wolpert, D., & Kawato, M. (2001). MOSAIC model for sensorimotor and learning control. *Neural Computation*, *13*, 2201–2220.

Holahan, A. L., & O’Driscoll, G. A. (2005). Antisaccade and smooth pursuit performance in positive- and negative-symptom schizotypy. *Schizophrenia Research*, *76*, 43–54.

Ivry, R. B., Spencer, R. M., Zelaznik, H. N., & Diedrichsen, J. (2002). The cerebellum and event timing. *Annals of the New York Academy of Sciences*, *978*, 302–317.

Jung-Beeman, M., Bowden, E., Haberman, J., Frymiare, J., Arambel-Liu, S., Greenblatt, R., et al. (2004). Neural activity when people solve verbal problems with insight. *PLOS Biology*, *2*, 500–510.

Karimi, Z., Windmann, S., Güntürkün, O., & Abraham A. (in press). Insight problem solving in individuals with high versus low schizotypy. *Journal of Research in Personality*.

Lavric, A., Forstmeier, S., & Rippon, G. (2000). Differences in working memory involvement in analytical and creative tasks: an ERP study. *Neuroreport*, *11*, 1613–1618.

Lenzenweger, M. F., & Gold, J. M. (2000). Auditory working memory and verbal recall memory in schizotypy. *Schizophrenia Research*, *42*, 101–110.

Lubow, R. E., & De la Casa, G. (2002). Latent inhibition as a function of schizotypality and gender: Implications for schizophrenia. *Biological Psychology*, *59*, 69–86.

Miller, B. L., Cummings, J., Mishkin, F., Boone, K., Prince, F., Ponton, M., & Cotman, C. (1998). Emergence of artistic talent in frontotemporal dementia. *Neurology*, *51*, 978–982.

Mohr, C., Graves, R. E., Gianotti, L. R. R., Pizzagalli, D., & Brugger, P. (2001). Loose but normal: A semantic association study. *Journal of Psycholinguistic Research*, *30*, 475–483.

Molle, M., Marshall, L., Lutzenberger, W., Pietrowsky, R., Fehm, H. L., & Born, J. (1996). Enhanced dynamic complexity in the human EEG during creative thinking. *Neuroscience Letters*, *208*, 61–64.

O’Driscoll, G. A., Lenzenweger, M. F., & Holzman, P. S. (1998). Antisaccades and smooth pursuit eye tracking and schizotypy. *Archives of General Psychiatry*, *55*, 837–843.

Park, S., & McTigue, K. (1997). Working memory and the syndromes of schizotypal personality. *Schizophrenia Research*, *26*, 213–220.

Ravizza, S. M., McCormick, C. A., Schlerf, J. E., Justus, T., Ivry, R. B., & Fiez, J. A. (2006). Cerebellar damage produces selective deficits in verbal working memory. *Brain*, *129*, 306–320.

Schuldberg, D. (2001). Six subclinical spectrum traits in normal creativity. *Creativity Research Journal*, *13*, 5–16.

Teasdale, J., Dritschel, B., Taylor, M., Proctor, L., Lloyd, C., Nimmo-Smith, I., & Baddeley, A. (1995). Stimulus-independent thought depends on central executive resources. *Memory & Cognition*, *23*, 551–559.

A. Abraham

Thompson-Schill, S. L. (2003). Neuroimaging studies of semantic memory: inferring “how” from “where.” *Neuropsychologia*, *41*, 280–292.

Wolpert, D.M., Doya, K., & Kawato, M. (2003). A unifying computational framework for motor control and social interaction.

Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences, *358*, 593–602.

Wolpert, D. M., & Flanagan, J. R. (2001). Motor prediction. *Current Biology*, *11*, R729–732.