

Hindsight 20/20: The future of laterality research

Georgina Donati^{a,b} and *Gillian S. Forrester^a

*Corresponding Author

^aDepartment of Psychological Sciences, Birkbeck, University of London, Malet Street, London, W1CE 7HX

^bDepartment of Psychiatry, University of Oxford, Warneford Hospital, Oxford, OX3 7JX

History: received: 2020-12-21 accepted: 2021-1-11

ABSTRACT

The last decade of laterality research has been bolstered by a significant broadening in theoretical framing and investigative approaches. Comparative research contributions continue to strengthen the position that ancient functional and anatomical brain biases are preserved in modern humans. However, how they unfold over developmental time and contribute to cognitive abilities is still unclear. To make further advances, we must position human brains and behaviors within an evolutionary framework. This includes viewing motor-sensory behavior as an integral part of a developing cognitive system.

Keywords: laterality, evolution, development

Data Availability Statement: N/A

In their review article “Laterality 2020: Entering the next decade”, Ocklenberg and colleagues (2020) reflect on the significant progress achieved in laterality research over the last decade and anticipate the themes that may dominate the new decade. While “Bridging the gap between laterality research in human subjects and non-human model species” makes an appearance as point 7, the development of human brain and behavioral biases within an evolutionary framework is integral to a better understanding of how cognition emerges in modern humans. Specifically, understanding why ancient asymmetric brain characteristics are preserved in modern humans, how they unfold and whether or not they impact cognition over developmental time are matters of critical importance. In order to progress the field of laterality research, we must recognize that we do not simply exist and interact with the natural world, but as animals, our bodies and our brains are a result of evolutionary processes.

Owing to comparative research, we acknowledge that the asymmetry patterns that exist across vertebrate species have been preserved throughout hominid evolution such that the majority of the population still possess a “standard” brain template. The right hemisphere and left side of the body are dominant for evaluating threat in the environment (e.g., predator avoidance), while the left hemisphere and right side of the body dominantly drive structured sequences of motor actions (e.g., feeding). In other species, the “divided brain” supports neural efficiency and parallel processing (Rogers, Vallortigara, & Andrew, 2013) -an “eat- and-not-be-eaten” parallel processor—if you will (Forrester, 2017).

It is possible that in modern humans, these ancient asymmetries are no longer required for survival, and therefore we find an increase in variation from the standard brain template with significant numbers of individuals possessing the standard divided survival biases crowded into a single hemisphere or reversed in orientation. However, research suggests that reversed brain organization occurs least frequently in the general population (reviewed in Vingerhoets, 2019) and that the frequency of reversed brain organization rises in populations of individuals with autism (e.g., Forrester, Davis, Malatesta, & Todd, 2020). Moreover, studies of infants and children have revealed positive relationships between the direction of behavioral biases and cognitive performance (Donati, Davis, & Forrester, 2020; Forrester et al., 2020; Forrester, Davis, Mareschal, Malatesta, & Todd, 2019).

Part of our journey going forward will be to evaluate if the convergence (Vingerhoets, 2019) of early lateralized motor-sensory and later related cognitive processes matter. For example, the early motor process of praxis and the later higher-order cognitive function of language share overlapping left-lateralized neural generators (Higuchi, Chaminade, Imamizu, & Kawato, 2009) in the majority of the population. One study has demonstrated that children with non-convergent biases (e.g., left hemisphere motor dominance but right hemisphere dominant language function) had significantly slower reading speed than children with convergent functions (e.g., both functions dominant in the left hemisphere) (Hernandez, Camacho-Rosales, Nieto, & Barroso, 1997). Does convergence strengthen cognitive fitness—or are other factors at play? We don't know.

The laterality literature does not currently distinguish between motor-sensory and higher-order cognitive function biases. Recent asymmetry reviews (Corballis, 2020; Rogers, 2020; Vallortigara & Rogers, 2020; Vingerhoets, 2019) demonstrate that basic motor-sensory behaviors (e.g., looking times and directions, manual speed, precision and accuracy) are evaluated on a par with higher-order cognitive abilities (e.g., maths, reading) with little consideration of how motor-sensory behavior and higher-order cognitive functions interact with each other developmentally. However, it is more complicated than a simple binary left–right brain organization distinction. In other species, the strength of hemisphere biases and associated contralateral behaviors are positively associated with fitness (e.g., survival) of the organism (MacNeilage, Rogers, & Vallortigara, 2009). We do not know if this is still true in humans. Therefore, it is necessary that we gain a better understanding of the role that early sensory-motor biases play in supporting the development of higher-order cognitive abilities (Donati et al., 2020; Forrester et al., 2019; Forrester et al., 2020; Forrester & Todd, 2018; Michel, Babik, Nelson, Campbell, & Marcinowski, 2013).

Some studies suggest that the strength of bias may be more important for cognitive development than the direction of the bias as an indication of functional specialization (Mellet et al., 2014). Healthy child populations tend to possess strong behavioral biases (regardless of direction), whereas the presence and strength of brain and behavioral biases decrease by comparison in some clinical populations (e.g., autism) (Donati et al., 2020; Floris et al., 2016; Forrester et al., 2020; Forrester, Pegler, Thomas, & Mareschal, 2014; Lindell & Hudry, 2013). However, studies that have focused primarily on adult participants have found inconsistent results including U-shaped relationships where cognitive performances were associated with mild to moderate lateralization and decreased with extreme lateralization (Boles, Barth, & Merrill, 2008; Hirnstein, Leask, Rose, & Hausmann, 2010) suggesting over specialization may be detrimental to cognitive flexibility. The literature additionally suggests that the strength of bias in one hemisphere does not predict the strength of bias for different functions in the other hemisphere (Hirnstein, Hausmann, & Güntürkün, 2008; for a review, see Rogers, 2020), further complicating possible explanations for determinants of the strength of bias.

It is difficult to know if mixed findings result from varying experimental methods or if factors associated with developmental stage are at play. The systematic mapping out of how cognition unfolds as part of a biased motor-sensory system may help us to understand both typical development and a range of neurodevelopmental disorders. Additionally, while there is little doubt that development plays an important role in the establishment of asymmetries over time, we still know too little about when biases develop and their influence on cognition. Some

research suggests that early motor-sensory biases are predisposed prior to birth (De Kovel et al., 2017; McCartney & Hepper, 1999) and lay the foundation for higher-order cognitive functions, as part of an integrated and dynamic cognitive system (Whyatt & Craig, 2012). An evolutionary-developmental perspective needs to be incorporated into the theoretical framework of the next generation of laterality investigations.

Unpicking the factors contributing to laterality patterns in brain organization and behaviors has yet to be accomplished—we've barely begun. Going forward, the relationships between motor-sensory and higher-order cognitive biases need to be addressed because they are critical to understanding (1) how cognition emerged/es over evolutionary and developmental time, (2) what developmental trajectories result in typical and atypical abilities in modern humans and research into these areas will (3) allow for the innovation of a new generation of early therapeutic interventions (e.g., Hutchon et al., 2019).

The next phase of laterality research will need to systematically investigate if asymmetry patterns influence the fitness of modern human cognition. In their review, Ocklenberg and colleagues (2020) highlight the need to address inconsistent methodological practices contributing to the replication crisis, consider the ecological validity of some laboratory-based studies and integrate non-W.E.I.R.D. datasets. In order to be successful, a necessary step change is required whereby experimenters challenge themselves to de-colonize and un-bias samples and samplers that contribute to our published body of literature.

The future success of laterality research lies in an inclusive, multi-disciplinary and multi-methodological approach. However, of equal importance is to acknowledge that it is neither necessary nor sufficient to evaluate human cognition in isolation of the rest of the animal kingdom, nor to consider cognition as a *product* in isolation of the motor-sensory *process* by which it emerges.

Disclosure statement

No potential conflict of interest was reported by the authors.

References

- Boles, D. B., Barth, J. M., & Merrill, E. C. (2008). Asymmetry and performance: Toward a neurodevelopmental theory. *Brain and Cognition*, 66, 124–139.
- Corballis, M. C. (2020). Bilaterally symmetrical: To be or not to be? *Symmetry*, 12(3), 326.
- De Kovel, C. G., Lisgo, S., Karlebach, G., Ju, J., Cheng, G., Fisher, S. E., & Francks, C. (2017). Left–right asymmetry of maturation rates in human embryonic neural development. *Biological Psychiatry*, 82(3), 204–212.
- Donati, G., Davis, R., & Forrester, G. S. (2020). Gaze behaviour to lateral face stimuli in infants who do and do not receive an ASD diagnosis. *Scientific Reports*, 10(1), 1–8.
- Floris, D. L., Barber, A. D., Nebel, M. B., Martinelli, M., Lai, M.-C., Crocetti, D., ... Mostofsky, S. H. (2016). Atypical lateralization of motor circuit functional connectivity in children with autism is associated with motor deficits. *Molecular Autism*, 7(1), 35.

- Forrester, G. S.** (2017). Hand, limb and other motor preferences: Methodological considerations. In: L. Rogers, & G. Vallortigara (eds) *Lateralized brain functions* (pp. 121–152). New York, NY: Humana Press.
- Forrester, G. S., Davis, R., Malatesta, G., & Todd, B. K.** (2020). Evolutionary motor biases and cognition in children with and without autism. *Scientific Reports*, 10(1), 1–10.
- Forrester, G. S., Davis, R., Mareschal, D., Malatesta, G., & Todd, B. K.** (2019). The left cradling bias: An evolutionary facilitator of social cognition? *Cortex*, 118, 116–131.
- Forrester, G. S., Pegler, R., Thomas, M. S., & Mareschal, D.** (2014). Handedness as a marker of cerebral lateralization in children with and without autism. *Behavioural Brain Research*, 268, 14–21.
- Forrester, G. S., & Todd, B.** (2018). Comparative approaches to lateral biases in social behaviour: A new perspective. In G. Forrester, K. Hudry, A. Lindell, & W. D. Hopkins (Eds.), *Cerebral lateralization and cognition: Evolutionary and developmental investigations of motor biases*. Progress in brain research book series (vol. 238, pp. 377–403). Amsterdam: Elsevier.
- Hernaandez, S., Camacho-Rosales, J., Nieto, A., & Barroso, J.** (1997). Cerebral asymmetry and reading performance: Effect of language lateralization and hand preference. *Child Neuropsychology*, 3(3), 206–225.
- Higuchi, S., Chaminade, T., Imamizu, H., & Kawato, M.** (2009). Shared neural correlates for language and tool use in Broca's area. *Neurology Reports*, 20(15), 1376–1381.
- Hirnstein, M., Hausmann, M., & Güntürkün, O.** (2008). The evolutionary origins of functional cerebral asymmetries in humans: Does lateralization enhance parallel processing? *Behavioural Brain Research*, 187(2), 297–303.
- Hirnstein, M., Leask, S., Rose, J., & Hausmann, M.** (2010). Disentangling the relationship between hemispheric asymmetry and cognitive performance. *Brain and Cognition*, 73, 119–127.
- Hutchon, B., Gibbs, D., Harniess, P., Jary, S., Crossley, S., Moffat, J. V., ... Basu, A. P.** (2019). Early intervention programmes for infants at high risk of atypical neurodevelopmental outcome. *Developmental Medicine & Child Neurology*, 61(12), 1362–1367.
- Lindell, A. K., & Hudry, K.** (2013). Atypicalities in cortical structure, handedness, and functional lateralization for language in autism spectrum disorders. *Neuropsychology Review*, 23(3), 257–270.
- MacNeilage, P. F., Rogers, L. J., & Vallortigara, G.** (2009). Origins of the left and right brain. *Scientific American*, 301(1), 60–67.
- McCartney, G., & Hepper, P.** (1999). Development of lateralized behaviour in the human fetus from 12 to 27 weeks' gestation. *Developmental Medicine and Child Neurology*, 41(2), 83–86.
- Mellet, E., Zago, L., Jobard, G., Crivello, F., Petit, L., Joliot, M., ... Tzourio-Mazoyer, N.** (2014). Weak language lateralization affects both verbal and spatial skills: An fMRI study in 297 subjects. *Neuropsychologia*, 65, 56–62.

Michel, G. F., Babik, I., Nelson, E. L., Campbell, J. M., & Marcinowski, E. C. (2013). How the development of handedness could contribute to the development of language. *Developmental Psychobiology*, 55(6), 608–620.

Ocklenburg, S., Berretz, G., Packheiser, J., & Friedrich, P. (2020). Laterality 2020: Entering the next decade. *Laterality*

Rogers, L. J. (2020). Asymmetry of motor behavior and sensory perception: Which comes first? *Symmetry*, 12(5), 690.

Rogers, L. J., Vallortigara, G., & Andrew, R. J. (2013). Divided brains. The biology and behaviour of brain asymmetries. New York, NY: Cambridge University Press.

Vallortigara, G., & Rogers, L. J. (2020). A function for the bicameral mind. *Cortex*, 124, 274–285.

Vingerhoets, G. (2019). Phenotypes in hemispheric functional segregation? Perspectives and challenges. *Physics of Life Reviews*, 30, 1–18.

Whyatt, C. P., & Craig, C. M. (2012). Motor skills in children aged 7–10 years, diagnosed with autism spectrum disorder. *Journal of Autism and Developmental Disorders*, 42(9), 1799–1809.