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Beaton, Alan A.; Richards, Gareth

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Where next for laterality research? Looking back and looking forward

Alan A. Beaton, Ph.D.[1,2] & Gareth Richards, Ph.D.[3*]

[1] Department of Psychology, School of Human & Health Sciences, Swansea University, Swansea, UK
[2] Department of Psychology, Aberystwyth University, Aberystwyth, UK
[1] School of Psychology, Faculty of Medical Sciences, Newcastle University, Newcastle upon Tyne, UK

* Corresponding author address: School of Psychology, Newcastle University, 4.32 Dame Margaret Barbour Building, Wallace Street, Richardson Road, Newcastle upon Tyne, NE2 4DR, UK; email: gareth.richards@ncl.ac.uk

Abstract
While paying attention to the recommendations of Ocklenburg et al. (2020) in the target article, researchers in the field of laterality should attempt to: 1) solve the long-standing puzzle of the relationship between handedness and language lateralization; 2) further explore the genetic bases of manual and cerebral asymmetry and of their associations with psychiatric and neurodevelopmental conditions; 3) explore the adaptive significance of laterality for humans and non-humans and elucidate the relationships of asymmetry across species; and 4) embrace developing technologies to investigate interaction between the hemispheres during the performance of everyday tasks.

We concur with the views expressed by Ocklenburg et al. (2020) in the target article. In particular, we agree that the cross-species study of laterality should be a major topic of research in the next decade. One aim might be to compare different primate species and humans, preferably from non-industrialised societies, on the same behavioural task to ascertain how manual preference and skill asymmetry vary within and between species. In addition, it would be instructive to look at task-related brain activation in different species performing the same task (de Schotten et al., 2019). A programme of comparative neuroimaging would help to identify the organisational principles whereby brains have adapted through convergent and divergent evolutionary processes (see Friedrich et al., 2021).

We distinguish between two classes of challenge for the future. One is to solve those long-outstanding problems that seem resistant to solution; the other is to tackle new problems arising from the development of new techniques.

Among the first category is "the puzzling relationship between language dominance and dominant hand" (Carey & Johnstone, 2014, p.1). Estimates of the frequency of atypical (right or bilateral) speech representation as a function of handedness have varied widely (Coppens et al., 2002). Two studies, each with samples of 100 or more participants (Springer et al., 1999; Mazoyer et al., 2014), reported very low incidences of right hemisphere speech. Springer et al. (1999, p.2040) stated that "fMRI in 100 right-handed, neurologically normal individuals failed to identify a single person with clear right hemisphere dominance", though 6% had "symmetric language representation". Similarly, Mazoyer et al. (2014) claimed not to find a single case of right-sided speech among 144 right-handers but they too observed cases

of “atypical” speech in 8 of these right-handers. They concluded that right hemisphere speech occurred only in left-handers and estimated a 0.6% prevalence for right hemisphere lateralization in the general population. Compare this with the proposal (based on consideration of the brain damage literature) that almost 10% of the general population has right cerebral dominance (Annett, 2002).

Mazoyer et al. (2014, p.13) refer to “the dogma of the existence of a correlation between hemispheric dominance for language and handedness”. They point out that the prevalence of right-handedness is approximately 90%, as is the prevalence of left hemisphere speech. As a result, a close correspondence between the two is to be expected by chance alone. They argue that their results (see also Packheiser et al., 2020) suggest that, if individuals with strongly atypical language lateralization are excluded, “the agreement between hemispheric dominance for hand preference and for language was barely above the chance level” (p.8).

Does any link with language lateralization relate to degree as well as direction of handedness? Functional transcranial Doppler sonography (Knecht, Dräger et al., 2000) and fMRI (Somers et al., 2015) studies have reported a relationship between direction and degree of handedness and an index of speech lateralization. However, to date it has been difficult to investigate the distribution of laterality indices of a truly representative sample of the population within a single study.

A common procedure has been to study only right-handers (e.g. Knecht, Deppe et al., 2000), only left-handers (e.g. Szaflarski et al., 2002) or to take two groups from opposite extremes of the laterality continuum (e.g. Mazoyer et al., 2014). As a consequence, individuals of intermediate hand preference, who comprise up to one third of the population (Annett, 2002), are excluded.

Rather than compute a correlation coefficient between indices of brain asymmetry and laterality quotients reflecting summed scores derived from a hand preference questionnaire (for critique see Beaton, 2003), it would be preferable in our view to use a measure of hand skill asymmetry. By dividing the laterality distribution into bins, one could examine the distribution of speech lateralization of participants across bins. Neuroanatomical asymmetries could be related to handedness in an analogous manner.

Given modern imaging methods, it should be possible in the next decade to derive sufficient data from neurologically healthy representative samples of the general population, along with adequate testing of handedness, to finally answer the question of precisely how, if at all, handedness and language lateralization are related. This will necessitate a concerted effort towards large-scale collaboration between research groups (see Kong et al., 2020). It is important to determine the nature of any relationship between handedness and speech dominance since absence of an association would imply that handedness and language lateralization are two independent characteristics with separate genetic underpinnings.

Within our second category of challenge, future research should continue the attempt to unravel the shared or independent genetic bases of cerebral and manual asymmetry (Cuellar-Partida et al., 2020; de Kovel & Franks, 2019), and of the associations between perturbations of laterality and psychiatric (Wiberg et al., 2019) and neurodevelopmental (Brandler & Paraschini, 2014) conditions. We see this as *the* major challenge for the next decade.

A further challenge is to determine the extent (if any) to which an asymmetrical brain is of fundamental importance for humans – as a species, and at an individual level. The purported advantages of having an asymmetrical brain have been widely discussed (Levy, 1974; Vallortigara & Rogers, 2020). We believe that developments in comparative neuroanatomy and comparative neuroimaging (Friedrich et al., 2021) will help shed light on the emergence of brain lateralization and thereby determine its significance for our own species.

At the level of the individual, both human and infra-human, many studies have attempted to relate aspects of asymmetry (including handedness) to levels of cognitive ability (Ntolka & Papadatou-Pastou, 2018) or to performance on specific tasks (Hirnstein et al., 2010). However, the possible implications of variation in direction and degree of multiple asymmetries for individual differences in cognition have barely been considered (but see Labache et al., 2020).

The wider question of whether there are any reproductive advantages associated with individual differences in cerebral lateralization has been deliberated in a few studies looking at Darwinian fitness in relation to handedness (see Faurie et al., 2006; Zickert et al., 2018). Might individuals with differing patterns of cerebral lateralization have developed different mating strategies, perhaps related to subtle differences in personality traits or abilities, and/or to aspects of female (McKeever et al., 2000; Zhu et al., 2009) or even male reproductive biology?

Our final proposed challenge for laterality researchers during the next decade is to understand more fully how the two hemispheres of the asymmetric brain interact to produce an exquisitely co-ordinated unity of behaviour and a unified (if not unity of) conscious experience (Pinto et al., 2017). We still have little idea how the two limbs are controlled from moment to moment when, for example, someone ties their shoelace, knots a tie, or swings a golf club. And how are the activities of the two sides of the brain co-ordinated in tasks which apparently require the specialised abilities of the two hemispheres acting in concert (think, for example, of reading sheet music while concentrating on getting right the rhythm, tempo, timbre, volume and emotional register of a piece of music)?

Despite the decline of so-called split-brain surgery, a focus on hemispheric interaction should be maintained. This will require novel ways of thinking how this might be explored in both humans and other species. Studies showing increased connectivity between and within the hemispheres in cases of agenesis of the corpus callosum (Mancuso et al., 2019) and application of dynamic network theory to neuroimaging studies (Doron et al., 2012) represent significant moves in this direction.

Data availability statement

The current manuscript does not include any new data.

References

Annett, M. (2002). *Handedness and brain asymmetry: The right shift theory*. Hove, Psychology Press. https://doi.org/10.4324/978/0203759646

Beaton, A. A. (2003). The nature and determinants of handedness. In: Hugdahl, K., & Davidson, R. J. (Eds.), *The asymmetrical brain*. Cambridge, MA: MIT Press. Chap. 4. pp. 105-158. https://doi.org/10.7551/mitpress/1463.003.0006

Brandler, W. M., & Paraschini, S. (2014). The genetic relationship between handedness and neurodevelopmental disorders. *Trends in Molecular Medicine, 20*(2), 83-90. https://doi.org/10.1016/j.molmed.2013.10.008

Carey, D. P., & Johnstone, L.T. (2014). Quantifying cerebral asymmetry for language in dextrals and adextrals with random-effects meta analysis. *Frontiers in Psychology, 5*, 1128. http://doi.org/10.3389/fpsyg.2014.01128

Coppens, P., Hungerford, S., Yamaguchi, S., & Yamadori, A. (2002). Crossed aphasia: An analysis of the symptoms, their frequency, and a comparison with left-hemisphere aphasia symptomatology. *Brain and Language, 83*(3), 425-463. https://doi.org/10.1016/s0093-934x(02)00510-2

Cuellar-Partida, G., Tung, J. Y., Eriksson, N., Albrecht, E., Aliev, F., Andreassen, O. A…Medland, S.E. (2020). Genome-wide association study identifies 48 common genetic variants associated with handedness. *Nature Human Behaviour*. https://doi.org/10.1038/s41562-020-00956-y

de Kovel, C. G. F., & Franks, C. (2019). The molecular genetics of hand preference revisited. *Scientific Reports, 9*, 5986. https://doi.org/10.1038/s41598-019-42515-0

de Schotten, M. T., Croxson, P. L., & Mars, R. B. (2019). Where are we and what do we think we need? *Cortex, 118*, 188-202. https://doi.org/10.1016/j.cortex.2018.11.028

Doron, K. W., Bassett, D. S., & Gazzaniga, M. S. (2012). Dynamic network structure of interhemispheric coordination. *Proceedings of the National Academy of Sciences of the United States of America, 109*(46), 18661-18668. https://doi.org/10.1073/pnas.1216402109

Faurie, C., Alvergne, A., Bonenfant, S., Goldberg, M., Hercberg, S., Zins, M., & Raymond, M. (2006). Handedness and reproductive success in two large cohorts of French adults. *Evolution and Human Behavior, 27*(6), 457-472. https://doi.org/10.1016/j.evolhumbehav.2006.04.001

Friedrich, P., Forkel, S. J., Amiez, C., Balsters, J. H., Coulon, O., Fan, L...de Schotten, T. (2021). Imaging evolution of the primate brain: The next frontier? *Neuroimage, 228*, 117685. https://doi.org/10.1016/j.neuroimage.2020.117685

Hirnstein, M., Leask, S., Rose, J., & Hausmann, M. (2010). Disentangling the relationship between hemispheric asymmetry and cognitive performance. *Brain and Cognition, 73*(2), 119-127. https://doi.org/10.1016/j.bandc.2010.04.002

Knecht, S., Deppe, M., Dräger, B., Bobe, L., Lohmann, H., Ringelstein, E.-B., & Henningsen, H. (2000). Language lateralization in healthy right-handers. *Brain, 123*(1), 74-81. https://doi.org/10.1093/brain/123.1.74

Knecht, S., Dräger, B., Deppe, M., Bobe, L., Lohmann, H., Flöel, A., Ringelstein, E.-B., & Henningsen, H. (2000). Handedness and language dominance in healthy humans. *Brain, 123*(12), 2512-2518. https://doi.org/10.1093/brain/123.12.2512

Kong, X.-Z., Postema, M. C., Guadalupe, T., de Kovel, C., Boedhoe, P. S. W., Hoogman, M…Francks, C. (2020). Mapping brain asymmetry in health and disease through the ENIGMA consortium. *Human Brain Mapping*. https://doi.org/10.1002/hbm.25033

Labache, L., Mazoyer, B., Joliot, M., Crivello, F., Hesling, I., & Tzourio-Mazoyer, N. (2020). Typical and atypical brain organization based on intrinsic connectivity and multitask functional asymmetries. *BioRχiv*. https://doi.org/10.1101/2020.05.07.083006

Levy, J. (1974). Psychobiological implications of bilateral asymmetry. In: Dimond, S. J., & Beaumont, J. G. (Eds.), *Hemisphere function in the human brain*. London: Elek Science. pp.121-183.

Mancuso, L., Uddin, L. Q., Nania, A., Costa, T., & Cauda, F. (2019). Brain functional connectivity in individuals with callosotomy and agenesis of the corpus callosum: A systematic review. *Neuroscience and Biobehavioral Reviews, 105*, 231-248. https://doi.org/10.1016/j.neubiorev.2019.07.004

Mazoyer, B., Zago, L., Jobard, G., Crivello, F., Joliot, M., Perchey, G…Tzourio-Mazoyer, N. (2014). Gaussian mixture modelling of hemispheric lateralization for language in a large sample of healthy individuals balanced for handedness. *PLoS ONE, 9*(6), e1011165. https://doi.org/10.1371/journal.pone.0101165

McKeever, W. F., Cerone, L. J., Suter, P. J., & Wu, S. M. (2000). Family size, miscarriage proneness, and handedness: Tests of hypotheses of the developmental instability theory of handedness. *Laterality: Asymmetries of Body, Brain and Cognition, 5*(2), 111-120. https://doi.org/10.1080/135765000396735

Ntolka, E., & Papadatou-Pastou, M. (2018). Right-handers have higher IQ scores than left-handers: Systematic review and meta-analyses. *Neuroscience and Biobehavioral Reviews, 84*, 376-393. https://doi.org/10.1016/j.neubiorev.2017.08.007

Ocklenburg, S., Berretz, G., Packheiser, J., & Friedrich, P. (2020). Laterality 2020: Entering the next decade. *Laterality: Asymmetries of Brain, Behaviour and Cognition*. https://doi.org/10.1080/1357650x.2020.1804396

Packheiser, J., Schmitz, J., Arning, L., Beste, C., Güntürkün, O. & Ocklenburg, S. (2020). A large-scale estimate on the relationship between language and motor lateralization. *Scientific Reports, 10*, (1), 13027. https://doi.org/10.1038/s41598-020-70057

Pinto, Y., Neville, D. A., Otten, M., Corballis, P. M., Lamme, V., de Haaan, E., Foschi, N., & Fabri, M. (2017). Split brain: Divided perception but undivided consciousness. *Brain, 140*(5), 1231-1237. http://doi.org/10.1093/brain/aww358

Somers, M., Aukes, M. F., Ophoff, R. A., Boks, M. P., Fleer, W., de Visser, K. C. L., Kahn, R. S., & Sommer, I. E. (2015). On the relationship between degree of hand-preference and degree of language lateralization. *Brain and Language, 144*, 10-15. https://doi.org/10.1016/j.bandl.2015.03.006

Springer, J. A., Binder, J. R., Hammeke, T. A., Swanson, S. J., Frost, J. A., Bellgowan, P. S. F…Mueller, W. M. (1999). Language dominance in neurologically normal and epilepsy subjects: A functional MRI study. *Brain, 122*(11), 2033-2046. https://doi.org/10.1093/brain/122.11.2033

Szaflarski, J. P., Binder, J. R., Possing, E. T., McKiernan, K. A., Ward, B. D., & Hammeke, T. A. (2002). Language lateralization in left-handed and ambidextrous people: fMRI data. *Neurology*, 59(2), 238-244. https://doi.org/10.1212/wnl.59.2.238

Vallortigara, G., & Rogers, L. J. (2020). A function for the bicameral mind. *Cortex, 124*, 274-285. https://doi.org/10.1016/j.cortex.2019.11.018

Wiberg, A., Ng, M., Al Omran, A., Alfaro-Almagro, F., McCarthy, P., Marchini, J…Furniss, D. (2019). Handedness, language areas and neuropsychiatric disease: Insights from brain imaging and genetics. *Brain, 142*(10), 2938-2947. https://doi.org/10.1093/brain/awz257

Zhu, J. L., Obel, C., Basso, O., Bech, B. H., Henriksen, T. B., & Olsen, J. (2009). Handedness and time to pregnancy. *Epidemiology, 20*(1), 52-55. https://doi.org/10.1097/ede.0b013e31818b47d1

Zickert, N., Geuze, R. H., van der Feen, F. E., & Groothuis, T. G. G. (2018). Fitness costs and benefits associated with hand preference in humans: A large Internet study in a Dutch sample. *Evolution and Human Behavior, 39*(2), 235-248. https://doi.org/10.1016/j.evolhumbehav.2018.01.001