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Manual dexterity correlating with right lobule VI volume in right-handed 14-year-olds

Simone Kühn [a,b,1], Alexander Romanowski [a,*,1], Christina Schilling [a,c], Tobias Banaschewski [d], Alexis Barbot [e], Gareth J. Barker [f], Rüdiger Brühl [g], Christian Büchel [h], Patricia J. Conrod [f], Katharina Czech [a], Jeff W. Dalley [i,j], Herta Flor [k], Hugh Garavan [l], Ines Häke [a], Bernd Ittermann [g], Nikolay Ivanov [a], Karl Mann [m], Mark Lathrop [n], Eva Loth [f], Katharina Lüdemann [a], Catherine Mallik [f], Jean-Luc Martinot [o,p], Carla Palafox [a], Jean-Baptiste Poline [e], Jan Reuter [a], Marcella Rietschel [q], Trevor W. Robbins [j], Michael N. Smolka [r,s], Frauke Nees [k], Bernadeta Walaszek [g], Gunter Schumann [f], Andreas Heinz [a], Jürgen Gallinat [a] and the IMAGEN consortium

[a] Department of Psychiatry and Psychotherapy, Charité University Medicine Campus Mitte, Berlin, Germany
[b] Department of Experimental Psychology and Ghent Institute for Functional and Metabolic Imaging, Ghent, Belgium
[c] Department of Psychology, Humboldt-Universität zu Berlin, Berlin, Germany
[d] Department of Child and Adolescent Psychiatry, Central Institute of Mental Health, Mannheim, Germany
[e] Neurospin, Commissariat à l'Energie Atomique, Paris, France
[f] King's College London, Institute of Psychiatry, London, UK
[g] Physikalisch-Technische Bundesanstalt, Braunschweig and Berlin, Germany
[h] Universitaetsklinikum Hamburg Eppendorf, Hamburg, Germany
[i] Department of Psychiatry, University of Cambridge, Cambridge, UK
[j] Department of Experimental Psychology, Behavioural and Clinical Neurosciences Institute, University of Cambridge, Cambridge, UK
[k] Department of Cognitive and Clinical Neuroscience, Central Institute of Mental Health, Mannheim, Germany
[l] Institute of Neuroscience, Trinity College Dublin, Dublin, Ireland
[m] Department of Addictive Behaviour and Addiction Medicine, Central Institute of Mental Health, Mannheim, Germany
[n] Centre National de Génotypage, Evry, France
[o] Institut National de la Santé et de la Recherche Médicale, INSERM Unit 1000 "Imaging & Psychiatry", SHFJ CEA, University Paris Sud, Orsay, France
[p] AP-HP Department of Adolescent Psychopathology and Medicine, Maison de Solenn, University Paris Descartes, Paris, France
[q] Department of Genetic Epidemiology in Psychiatry, Central Institute of Mental Health, Mannheim, Germany
[r] Department of Psychiatry and Psychotherapy, Technische Universität Dresden, Dresden, Germany
[s] Neuroimaging Center, Department of Psychology, Technische Universität Dresden, Dresden, Germany

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ABSTRACT

Background: Dexterity is a fundamental skill in our everyday life. Particularly, the fine-tuning of reaching for objects is of high relevance and crucially coordinated by the cerebellum. Although neuronal cerebellar structures mediate dexterity, classical whole brain voxel-based morphometry (VBM) has not identified structural correlates of dexterity in the cerebellum.

Methods: Clusters of gray matter (GM) volume associated with the Purdue Pegboard Dexterity Test, a test of fine motor skills and complex upper limb movements, were identified in a cerebellum-optimized VBM analysis using the Spatially Unbiased Infratentorial (SUIT) toolbox in 65 healthy, right-handed 14-year-olds. For comparison, classical whole brain VBM was performed.

Results: The cerebellum-optimized VBM indicated a significant positive correlation between manual dexterity and GM volume in the right cerebellum Lobule VI, corrected for multiple comparisons and non-stationary smoothness. The classical whole brain VBM revealed positive associations (uncorrected) between dexterity performance and GM volume in the left SMA (BA 6), right fusiform gyrus (BA 20) and left cuneus (BA 18), but not cerebellar structures.

Abbreviations: BA, Brodman area; CT, Cortical thickness; FDR, false discovery rate; fMRI, Functional magnetic resonance imaging; GM, Gray matter; rCBF, regional cerebral blood flow; ROI, region of interest; SMA, supplementary motor area; SUIT, Spatially Unbiased Infratentorial (SUIT) toolbox; VBM, Voxel based morphometry.

* Corresponding author.
E-mail address: alexander.romanowski@charite.de (A. Romanowski).

[1] These authors contributed equally.

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Conclusions: The results indicate that cerebellar GM volumes in the right Lobule VI predict manual dexterity in healthy untrained humans when cerebellum-optimized VBM is employed. Although conventional VBM identified brain motor network areas it failed to detect cerebellar structures. Thus, previous studies might have underestimated the importance of cerebellum in manual dexterity.

Introduction

Manual dexterity is a complex primate attribute with reaching and grasping for objects being one of the most frequent daily actions. Human manual skills constitute the fundament of tool use and cultural development whilst its disturbances can cause severe impairment in daily life. In order to execute goal-directed movements, the brain must specify the position of the target in an egocentric frame of reference by integrating external signals (e.g. visual and auditory stimuli) with intrinsic signals (proprioceptive, vestibular, motor) related to body, arm, head and eye position. Dexterity depends on a continuous flow of information from the cerebral cortex to the spinal cord and provides a precise, dynamic representation of the external world. Previous electrophysiological investigations in nonhuman primates as well as functional neuroimaging studies in humans have defined a broad range of cortical areas being active during goal-directed grasping. In particular, several frontal cortical motor areas involved in hand control were identified in nonhuman primates (He et al., 1993; Hepp-Reymond et al., 1994; Muakkassa and Strick, 1979). Cerebellar involvement in prehensile movements has been shown by Smith et al. (1993) in their neurophysiological work. Furthermore, functional imaging reach-to-grasp studies have reported cerebellar activation (Begliomini et al., 2007; Chapman et al., 2002; Grafton et al., 1996a,b; Rizzolatti et al., 1988, 1996). Additionally, Miall and Christensen (2004) has shown increased movement times in pegboard task induced by repetitive transcranial magnetic stimulation over the right cerebellum. In general, the involvement of the cerebellum in sensorimotor control, balance and motor speech is well investigated, yet primarily based on observation of deficits resulting from cerebellar lesions (Flourens, 1824; Holmes, 1939; Luciani, 1891). In particular, several abnormalities of all components of prehensile movements, such as increased path curvatures, corrective movements, variable wrist velocity profiles and a general lower velocity of movement execution were observed in cerebellar patients (Bastian and Thach, 1995; Haggard et al., 1994; Timmann et al., 1999, 2001; Zackowski et al., 2002). A number of previous studies on object manipulation have reported, that patients with cerebellar degeneration exhibit higher grip forces compared to controls (Babin-Ratte et al., 1999; Rost et al., 2005; Serrien and Wiesendanger, 1999).

However, up to now no systematic structural brain imaging investigation (e.g. voxel-based morphometry (VBM)) in healthy untrained subjects has focused on cerebellar gray matter correlates underlying the complex performance of manual dexterity.

We chose the performance score of the pegboard dexterity test assessing the coordination of goal-directed precise movements, a measure associated with a well replicated relationship between behavioral performance and cerebellar function (Haggard et al., 1994; Johnson-Greene et al., 1997; Maltz and Goldberg, 1982). This test involves unilateral and bilateral hand movements guided and coordinated by visual stimuli under time pressure. We predicted that pegboard task performance involves brain regions associated with complex grasping and reaching movements rather than regions required for simpler tasks such as finger tapping (Desmond et al., 1997). Both cortical and subcortical regions have been found to be involved in completing similar tasks in functional neuroimaging (Begliomini et al., 2007; Chapman et al., 2002; Grafton et al., 1996a,b; Rizzolatti et al., 1996; Shibasaki et al., 1993). In those experiments increased activation of primary sensorimotor cortex, premotor cortices as well as of the caudal part of supplementary motor area (SMA) , the right posterior cerebellum and occipital visual cortices was observed. In particular, Desmond et al. (1997) have reported cerebellar activation in lobule IV, V and VI during finger taping in functional magnetic resonance imaging (fMRI). In line with those functional findings, we expected corresponding structural gray matter correlates in these lobules in our study. VBM studies have reported distinct structural correlates in the cerebellum only in highly trained typists (Cannonieri et al., 2007) and musicians (Gaser, 2003), but not golfers (Jäncke et al., 2009). Draganski et al. (2004) have reported no GM changes induced by juggling training in the cerebellum in their VBM studies. To the knowledge of the authors, no previous study has demonstrated an association between manual dexterity and cerebellar morphometry in samples not restricted to specific as well as highly trained participants in a large sample.

The specific anatomy of the cerebellum including thinner striations of gray and white matter as well as less obvious demarcations compared to cortical structures pose a particular methodological challenge to ordinary whole brain VBM. Thus, in order to provide an optimized analysis of structural correlates in the cerebellum we applied an optimized normalization by using the Spatially Unbiased Infratentorial (SUIT) toolbox (http://www.icn.ucl.ac.uk/motorcontrol/imaging/suit.htm, Diedrichsen, 2006).

Material and methods

Participants

Sixty five 14-year-olds (*M* 14.4 years; *SD* 0.32 years; 44 females) volunteered for this study within the scope of the IMAGEN project (Schumann et al., 2010). Written informed consent was obtained from all participants as well as from their legal guardians. The adolescents were recruited from secondary schools in Berlin, Germany. The assessment was approved by the assigned ethics committee. Participants with a medical condition such as a tumor, neurological disorders such as epilepsy or mental-health problems like affective disorders were excluded. All participating students were screened by means of both a self rating and two external ratings (parents; psychiatrists specialized in pediatrics) as part of a scale tailored to adolescents and based on ICD-10 as well as DSM-IV (The Development and Well-Being Assessment Interview; Goodman et al., 2000). All participants included were right-handed.

Manual dexterity measure

As part of the behavioral assessment within the IMAGEN study the participants were asked to perform the Purdue Pegboard Dexterity Test to assess hand dexterity as well as fine motor skills and complex upper limb movements (Gardner and Broman, 1979). After explanation as well as demonstration of the task and some practice trials prior to all three conditions, participants were asked to place as many pins into the holes of the perforated board as possible within 30 s of each trial. Three trials per condition were administered, starting with the dominant (right) hand, subsequently using the non-dominant hand and finally using both hands simultaneously. By averaging the number of pins placed correctly over the trials