Citation for published version (APA):
Genome-wide analysis of genetic correlation in dementia with Lewy bodies, Parkinson's and Alzheimer's diseases

Rita Guerreiro a,2, Valentina Escott-Price b,2, Lee Darwent a, Laura Parkkinen c, Olaf Ansorge c, Dena G. Hernandez d,e, Michael A. Nalls d, Lorraine Clark f,g, Lawrence Honig f,g, Karen Marder h,i, Wiesje van der Flier i, Henne Holstege i, Eva Louwersheimer i, Afina Lemstra i, Philip Scheltens j, Ekaterina Roaeva i, Peter St George-Hyslop k,l, Elisabet Londos i, Henrik Zetterberg m,a, Sara Ortega-Cubero n,o, Pau Pastor p,q, Tanis J. Ferman q, Neill R. Graff-Radford r, Owen A. Ross s, Imelda Barber t, Anne Braae t, Kristel Brown t, Kevin Morgan t, Walter Maetzler u, Daniela Berg v, Claire Troakes v, Safa Al-Sarraj v, Tammyrin Lashley w, Yaroslau Compton w,x, Tamas Revesz w, Andrew Lees w, Nigel J. Cairns y, Glenda M. Halliday z,aa, David Mann bb, Stuart Pickering-Brown bb, John Powell cc, Katie Lunnon dd, Michelle K. Lupton cc, International Parkinson's Disease Genomics Consortium (IPDGC) i, Dennis Dickson s, John Hardy ee, Andrew Singleton d, Jose Bras a,.*

a Department of Molecular Neuroscience, Institute of Neurology, UCL, London, UK
b MRC Centre for Neuropsychiatric Genetics and Genomics, School of Medicine, Cardiff University, Cardiff, UK
c Nuffield Department of Clinical Neurosciences, Oxford Parkinson's Disease Centre, University of Oxford, Oxford, UK
d Laboratory of Neurogenetics, National Institutes on Aging, NIH, Bethesda, MD, USA
e German Center for Neurodegenerative Diseases (DZNE), Tuebingen, Germany
f Taub Institute for Alzheimer Disease and the Aging Brain, Columbia University, New York, NY, USA
g Department of Pathology and Cell Biology, Columbia University, New York, NY, USA
h Department of Neurology, University of California at San Francisco, San Francisco, CA, USA
i Department of Neurology, Mayo Clinic, Jacksonville, FL, USA
j Department of Neurology, University of Pittsburgh, Pittsburgh, PA, USA
k Department of Molecular Neuroscience, Institute of Neurology, UCL, London, UK
l Department of Clinical Neurosciences, Oxford Parkinson's Disease & Movement Disorders Unit, Neurology Service, Clinical Neuroscience Institute (ICN), Hospital Clínic/University of Barcelona/IDIBAPS, Barcelona, Spain
m Department of Neurology, Knight Alzheimer’s Disease Research Center, Washington University School of Medicine, Saint Louis, MO, USA
n Department of Pathology and Cell Biology, Columbia University, New York, NY, USA
o Department of Psychiatry and Psychology, Mayo Clinic, Jacksonville, FL, USA
p Department of Neuroscience, Mayo Clinic, Jacksonville, FL, USA
q Department of Basic and Clinical Neuroscience, Institute of Psychiatry, Psychology and Neuroscience, King's College London, London, UK
r Department of Clinical Neurochemistry Laboratory, Department of Psychiatry and Neurochemistry, Institute of Neuroscience and Physiology, Sahlgrenska Academy at the University of Gothenburg, Gothenburg, Sweden
s MRC London Neurodegenerative Diseases Brain Bank, Institute of Psychiatry, Department of Clinical Neuroscience, King’s College London, London, UK
t Hertie Institute for Clinical Brain Research, Department of Neurodegeneration, Center of Neurology, University of Tuebingen, and DZNE, German Center for Neurodegenerative Diseases, Tuebingen, Germany
u School of Medical Sciences, Faculty of Medicine, University of Queensland, Brisbane, Australia
v MRC Centre for Neuropsychiatric Genetics and Genomics, School of Medicine, Queens Medical Centre, University of Nottingham, Nottingham, UK
w Institute of Psychiatry, Psychology and Neuroscience, King’s College London, London, UK
x Laboratory of Neurogenetics, National Institutes on Aging, NIH, Bethesda, MD, USA
y Department of Neurology, University of California at San Francisco, San Francisco, CA, USA
z School of Medical Sciences, Faculty of Medicine, University of Sydney, Sydney, Australia
aa Dalhousie University, Halifax, Nova Scotia, Canada
b National Institute of Neurological Disorders and Stroke, National Institutes of Health, Bethesda, MD, USA
c Division of Human Genetics, School of Life Sciences, Queens Medical Centre, University of Nottingham, Nottingham, UK
d Department of Clinical Neurochemistry, Department of Clinical Neurosciences, Oxford Parkinson’s Disease & Movement Disorders Unit, Clinical Neuroscience Institute (ICN), Hospital Clínic/University of Barcelona/IDIBAPS, Barcelona, Spain

*Corresponding author at: Department of Molecular Neuroscience, Institute of Neurology, University College of London, 8-11 Queen Square, DRC, Box 16, London, WC1N 3AR, UK. Tel.: +44 203 448 3936.
E-mail address: j.bras@ucl.ac.uk (J. Bras).

2 Equally contributing authors.

A complete list of the IPDGC members is listed in the Supplementary Material.

http://dx.doi.org/10.1016/j.neurobiolaging.2015.10.028
The similarities between dementia with Lewy bodies (DLB) and both Parkinson’s disease (PD) and Alzheimer’s disease (AD) are many and range from clinical presentation, to neuropathological characteristics, to more recently identified, genetic determinants of risk. Because of these overlapping features, diagnosing DLB is challenging and has clinical implications since some therapeutic agents that are applicable in other diseases have adverse effects in DLB. Having shown that DLB shares some genetic risk with PD and AD, we have now quantified the amount of sharing through the application of genetic correlation estimates, and show that, from a purely genetic perspective, and excluding the strong association at the APOE locus, DLB is equally correlated to AD and PD.

© 2016 The Authors. Published by Elsevier Inc. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).

1. Introduction

As we move toward an era where precision medicine becomes a reality, being able to confidently differentiate between closely related diseases is fast becoming a key priority. This is even more relevant when therapeutic approaches from one disease have negative effects when used in patients from another, as is the case in dementia with Lewy bodies (DLB) where neuropsychiatric and dysautonomic features can be worsened by dopaminergic agents used in Parkinson’s disease (PD; Zweig and Galvin, 2014).

DLB is probably one of the most underserved common disorders and much of this stems from the fact that it is a disease for which a clinical diagnosis is a particularly difficult one to make as DLB can be misdiagnosed as Alzheimer’s disease (AD) when starting with cognitive impairment or as PD when presenting with parkinsonism, and in turn PD can be easily mistaken as DLB if parkinsonism is overlooked. There are numerous shared aspects between DLB and the other more common neurodegenerative diseases PD and AD. This is not only true at the clinical level (particularly in the case of DLB and PD, to the point that an artificial and arbitrary “one-year-rule” in terms of the timing between parkinsonism and dementia has been needed to delineate them), but also, to some extent, at the pathological level, where Lewy bodies are a common characteristic of both DLB and PD, and beta-amyloid plaques and tau-positive neurofibrillary tangles, hallmarks of AD, often coexist in DLB and PD brains leading to the suggestion of a synergism between these pathologies (Compta et al., 2011; McKeith et al., 2005).

It is key that we have a better understanding of the molecular mechanisms occurring in DLB, not only because this is pivotal information for novel therapies to be developed for this disease, but also because it will help us gain a better understanding of PD, particularly when associating dementia, and AD.

We have recently performed a large-scale genetic analysis in DLB that showed similarities in common genetic risk between this disease, PD, and AD (Bras et al., 2014) using NeuroX, a genome-wide genotyping array (Nalls et al., 2015). To better understand and quantify these similarities we have now estimated the proportion of variance explained by all single nucleotide polymorphisms of the DLB cohort, and of independent AD and PD cohorts of similar size. We then performed a bivariate restricted maximum likelihood analysis of the genetic relationship matrix, to quantify the genetic covariance between pairs of diseases.

2. Methods

Details of the DLB cohort have been published previously (Bras et al., 2014). We used a cohort of 804 European PD cases and a cohort of 959 clinically diagnosed European AD cases, as well as 2806 European and North-American controls, genotyped on Illumina’s NeuroX. The PD samples are a UK-only subset of the previously published PD and control dataset (Nalls et al., 2014). The AD cases were diagnosed as either definite or probable AD according to National Institute of Neurological and Communicative Disorders and Stroke and the Alzheimer’s disease and Related Disorders Association (McKhann et al., 1984), and the Consortium to Establish a Registry for Alzheimer’s disease guidelines (Mirra et al., 1991). All samples used in this study were received with informed consents approved by the local Ethics Committees (Table 1).

Following standard raw data quality control procedures, which included removing variants with GenTrain scores (a metric to assess genotyping quality) lower than 0.9 and samples with call rate lower than 90% (meaning that samples that had less than 90% of the markers genotyped were excluded), we removed markers that had a genotyping rate of >10% and a minor allele frequency of <3%. To generate covariates for the analysis, multidimensional scaling was used to quantify genetic distances between members of the entire cohort.

After estimating the genetic relationship matrix between pairs of individuals, we performed a bivariate restricted maximum likelihood analysis on that matrix, as implemented in the software genome-wide complex trait analysis (Lee et al., 2012; Yang et al., 2010) using the first 2 principal components from multidimensional scaling.

For each comparison the control population was randomized and 1403 controls were assigned to each disease. The analysis between DLB and AD was then repeated excluding markers in the APOE region.

3. Results

When using the entire array content, after quality control procedures, the estimates for the proportion of variance explained by all single nucleotide polymorphisms for DLB was 0.31 (SE ± 0.03), for PD was 0.28 (SE ± 0.05), and for AD was 0.6 (SE ± 0.05), and for PD was 0.28 (SE ± 0.05). When excluding the APOE region, the estimates were 0.22 (SE ± 0.03), 0.42 (SE ± 0.05), and 0.28 (SE ± 0.05), for DLB, AD, and PD. The decrease seen in DLB and AD reflect the strong and robust association of the APOE locus in these diseases.

When comparing pairs of diseases for genetic correlation (i.e., estimating the additive genetic effect i.e., shared between pairs of traits), the highest score was obtained for the AD/DLB pair (0.578, SE ± 0.075). The comparison between PD or DLB yielded a correlation score of 0.362 (SE ± 0.107). Both scores were highly significant with p-values of 1.1 ×10−12 and 7.1 × 10−4, respectively. As a control experiment, we compared AD/PD and obtained a significantly lower score 0.08 (SE ± 0.101) (p-value = 0.006, with the most conservative estimate provided
by the cocor.dep.groups.overlap function from the cocor package in R, a test of significance for the difference between 2 correlations based on dependent groups with 1 variable in common), that does not deviate from the null hypothesis of no correlation (p-value = 0.39).

Given the strong effect from APOE in AD and DLB, we have performed the same analysis excluding this locus in these 2 cohorts and obtained a correlation score for AD/DLB_NO_APOE (0.332 ± 0.106) that is not statistically different from the PD/DLB correlation (0.362 ± 0.107) (p-value = 0.761, using the same test as mentioned previously). The AD/DLB_NO_APOE correlation is still highly significant 1.8 × 10⁻¹¹ (Table 2).

4. Discussion

We have previously described that DLB shares genetic risk determinants with both PD and AD. Here we quantify that overlap by showing that these diseases are, in fact, correlated from a purely genetic perspective.

The DLB cohort is the largest reported so far and a majority of these cases are neuropathologically confirmed (85%), which greatly increases the diagnostic accuracy (Bras et al., 2014). The numbers of PD and AD cases in this study are small, particularly when in comparison with other published datasets. We should note, however, that the fact that we fully replicate the phenotypic variance associated with all types of PD from large meta-analysis studies (Keller et al., 2012), suggests these cohorts are representative, and not substantially underpowered for this type of analysis. In addition, our data shows no genetic correlation between PD and AD (correlation = 0.08, SE = 0.101, p-value = 0.39 when correlation is fixed at 0), a result that replicates previous independent findings (Moskina et al., 2013).

It should be noted that although being a genome-wide array, NeuroX is not a completely unbiased genotyping platform. A proportion of the variants assayed in this array were included because they were known to be involved in these diseases. Because of this, some of these values may be inflated, however, for the purposes of determining genetic correlation, and comparing between pairs of diseases, this should have no discernible effect.

That DLB seems to share approximately the same amount of genetic risk determinants with PD and AD fits with our understanding of this disease, given the clinical and neuropathological overlap. Although not assessed in this work, it would be interesting to test if these correlations reflect quantitative pathology (e.g., would excluding DLB cases with prominent AD-related pathology reduce the correlation score between DLB and AD).

5. Conclusions

This is the first study to look at genetic correlation between DLB, PD, and AD. Despite using small cohorts, we show that these data replicate previously published results. We also show that DLB shares approximately the same amount of genetic determinants with PD as it does with AD, when the APOE locus is excluded. These results show us that, from a mechanistic standpoint, DLB is a different, but highly related disease to both AD and PD. They further emphasize the need for more studies in DLB—this is a greatly underappreciated disease and these data strongly support this fact.

Fully dissecting the genetic architecture of DLB will allow us to gain a better understanding of not just one but all 3 diseases. In addition, these data also show that we should gradually move from the current model of binary diagnosis to a more quantitative one.

Disclosure statement

The authors have no conflicts of interest to disclose.

Acknowledgements

Rita Guerreiro and Jose Bras are supported by Research Fellowships from the Alzheimer’s Society. This work was supported in part by a Parkinson’s UK Innovation Award (K-1204) in collaboration with the Lewy Body Society and by the Wellcome Trust/MRC Joint Call in Neurodegeneration award (WT089608) to the UK Parkinson’s Disease Consortium whose members are from the UCL Institute of Neurology, the University of Sheffield, and the MRC Protein Phosphorylation Unit at the University of Dundee and by an anonymous Foundation. The authors would like to acknowledge Elena Lorenzo for her technical assistance. This study was supported in part by grants from the Spanish Ministry of Science and Innovation SAF2006-10126 (2006–2009) and SAF2010-22329-C02-01 (2011–2013) and SAF2013-47939-R (2013–2015) to Pau Pastor and by the UTE project FIMA to Pau Pastor. They acknowledge the Oxford Brain Bank, supported by the Medical Research Council (MRC), Brains for Dementia Research (BDR) (Alzheimer Society and Alzheimer Research UK), Autistica UK, and the NIHR Oxford Biomedical Research Centre. The sample collection and database of the Amsterdam Dementia Cohort was funded by Stichting Dierfonds and Stichting VUMC fonds. Glenda M. Halliday is a Senior Principal Research Fellow of the National Health and Medical Research Council of Australia. For the neuropathologically confirmed samples from Australia, brain tissue was received from the Sydney Brain Bank, which is supported by Neuroscience Research Australia, the University of New South Wales, and the National Health and Medical Research Council of Australia. This study was also partially funded by the Wellcome Trust, Medical Research Council, Canadian Institutes of Health Research, Ontario Research Fund. The Nottingham Genetics Group is supported by ARUK and The Big Lottery Fund. The effort from Columbia University was supported by the Taub Institute, the Panasici Fund, the Parkinson’s Disease Foundation, and NIH grants NS060113 (Lorraine Clark), P50AG080702 (P.I. Scott Small), P50NS083370 (P.I. R. Burke), and U1LTR000040 (P.I. H. Ginsberg). Owen A. Ross is supported by the Michael J. Fox Foundation, NINDS R01# NS078086. The Mayo Clinic Jacksonville is a Morris K. Udall Parkinson’s Disease Research Center of Excellence (NINDS P50 #NS072187) and is supported by the Mangurian Foundation for Lewy body research. This work has received support from The Queen Square Brain Bank at the UCL Institute of Neurology. Some of the tissue samples studies were provided by the MRC London Neurodegenerative Diseases Brain Bank and the Brains for Dementia Research project (funded by Alzheimer’s Society and ARUK). This research was supported in part

<table>
<thead>
<tr>
<th>Trait</th>
<th>Total cases</th>
<th>Pathologically confirmed cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>DLB</td>
<td>788</td>
<td>667</td>
</tr>
<tr>
<td>AD</td>
<td>959</td>
<td>113</td>
</tr>
<tr>
<td>PD</td>
<td>804</td>
<td>0</td>
</tr>
</tbody>
</table>

Key: AD, Alzheimer’s disease; DLB, dementia with Lewy bodies; PD, Parkinson’s disease.

<table>
<thead>
<tr>
<th>Trait1</th>
<th>Trait2</th>
<th>Genetic correlation</th>
<th>SE</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>AD</td>
<td>DLB</td>
<td>0.578</td>
<td>0.075</td>
<td>1.1 × 10⁻¹²</td>
</tr>
<tr>
<td>PD</td>
<td>DLB</td>
<td>0.362</td>
<td>0.107</td>
<td>7.1 × 10⁻⁴</td>
</tr>
<tr>
<td>AD</td>
<td>PD</td>
<td>0.08</td>
<td>0.101</td>
<td>0.39</td>
</tr>
<tr>
<td>AD</td>
<td>DLB_NO_APOE</td>
<td>0.332</td>
<td>0.106</td>
<td>1.8 × 10⁻³</td>
</tr>
</tbody>
</table>

Key: AD, Alzheimer’s disease; DLB, dementia with Lewy bodies; PD, Parkinson’s disease; SE, standard error.
by the NIHR UCLH Biomedical Research Centre, the Queen Square Dementia Biomedical Research Unit, the National Institute for Health Research (NIHR) Dementia Biomedical Research Unit and Biomedical Research Centre at South London and Maudsley NHS Foundation Trust and King’s College Hospital, London. This work was supported in part by the Intramural Research Program of the National Institute on Aging, National Institutes of Health, Department of Health and Human Services; project AG00951-12. Funding to pay the Open Access publication charges for this article was provided by the Wellcome Trust and the Medical Research Council.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.neurobiolaging.2015.10.028.

References


