Author Correction: A Human Neuroimaging Perspective on Sleep in Normative and Pathological Ageing

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The original version of this article contained a mistake. In the recently published paper, “A Human Neuroimaging Perspective on Sleep in Normative and Pathological Ageing”, there were errors in Table 1 and reference list.

The correct Table 1 and reference list are shown in this article.

The authors apologize for this oversight and for any confusion it may have caused.

Table 1 Prevalence of sleep disorders in the general population, older adults and neurodegenerative diseases

	Insomnia disorder	Sleep-disordered breathing	REM sleep behaviour disorder
General population	9–10% ^a	33% ^c - 36% ^f	1% ^h
Older adults (60+ years)	9% ^b	50% ^f - 73% ^e	2% ⁱ
Neurodegenerative disease	27% ^c - 52% ^d (all cause dementia)	50% ^g - 54% ^d (Alzheimer’s disease) 75% ^d (Vascular dementia)	42% ^j (Parkinson’s disease) 95% ^{k,l} (Dementia with Lewy Bodies)

^a [53], ^b [52], ^c [167], ^d [55], ^e [76], ^f [74], ^g [82], ^h [168], ⁱ [169], ^j [124], ^k [125], ^l [126]

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References

1. Tononi G, Cirelli C. Sleep and the price of plasticity: from synaptic and cellular homeostasis to memory consolidation and integration. *Neuron*. 2014;81(1):12–34.
2. Born J, Wilhelm I. System consolidation of memory during sleep. *Psychol Res*. 2012;76(2):192–203.
3. Xie L, Kang H, Xu Q, Chen MJ, Liao Y, Thiyagarajan M, et al. Sleep drives metabolite clearance from the adult brain. *Science (New York, NY)*. 2013;342(6156):373–7.
4. Mander BA, Winer JR, Walker MP. Sleep and human aging. *Neuron*. 2017;94(1):19–36.
5. Scullin MK. Do older adults need sleep? A review of neuroimaging, sleep, and aging studies. *Curr Sleep Med Rep* 2017;3(3): 204–14.
6. Uchida S, Shioda K, Morita Y, Kubota C, Ganeko M, Takeda N. Exercise effects on sleep physiology. *Front Neurol*. 2012;3:48.

7. Carrier J, Bliwise D. Sleep and circadian rhythms in normal aging. In: Billiard M, editor. *Sleep: physiology, investigations, and medicine*. Boston, MA: Springer US; 2003. p. 297–332.
8. Gaudreau H, Carrier J, Montplaisir J. Age-related modifications of NREM sleep EEG: from childhood to middle age. *J Sleep Res*. 2001;10(3):165–72.
9. Van Cauter E, Leproult R, Plat L. Age-related changes in slow wave sleep and REM sleep and relationship with growth hormone and cortisol levels in healthy men. *JAMA*. 2000;284(7):861–8.
10. Carrier J, Land S, Buysse DJ, Kupfer DJ, Monk TH. The effects of age and gender on sleep EEG power spectral density in the middle years of life (ages 20–60 years old). *Psychophysiology*. 2001;38(2):232–42.
11. Mourtazaev MS, Kemp B, Zwiderman AH, Kamphuisen HA. Age and gender affect different characteristics of slow waves in the sleep EEG. *Sleep*. 1995;18(7):557–64.
12. Martin N, Lafortune M, Godbout J, Barakat M, Robillard R, Poirier G, et al. Topography of age-related changes in sleep spindles. *Neurobiol Aging*. 2013;34(2):468–76.
13. Clawson BC, Durkin J, Aton SJ. Form and function of sleep spindles across the lifespan. *Neural Plast*. 2016;2016:6936381.
14. Crowley K, Trinder J, Kim Y, Carrington M, Colrain IM. The effects of normal aging on sleep spindle and K-complex production. *Clin Neurophysiol*. 2002;113(10):1615–22.
15. Spira AP, Gonzalez CE, Venkatraman VK, Wu MN, Pacheco J, Simonsick EM, et al. Sleep duration and subsequent cortical thinning in cognitively Normal older adults. *Sleep*. 2016;39(5):1121–8. **This study provides evidence that subjective short and long sleep duration predicts decreased cortical thickness in frontal and temporal areas of the brain.**
16. Moscovitch M, Winocur G. Frontal lobes, memory, and aging. *Ann N Y Acad Sci*. 1995;769:119–50.
17. West RL. An application of prefrontal cortex function theory to cognitive aging. *Psychol Bull*. 1996;120(2):272–92.
18. Gildner TE, Liebert MA, Kowal P, Chatterji S, Snodgrass JJ. Associations between sleep duration, sleep quality, and cognitive test performance among older adults from six middle income countries: results from the study on global ageing and adult health (SAGE). *J Clin Sleep Med*. 2014;10(6):613–21.
19. Bliwise DL, Young TB. The parable of parabola: what the U-shaped curve can and cannot tell us about sleep. *Sleep*. 2007;30(12):1614–5.
20. Weber M, Webb CA, Deldorno SR, Kipman M, Schwab ZJ, Weiner MR, et al. Habitual ‘sleep credit’ is associated with greater grey matter volume of the medial prefrontal cortex, higher emotional intelligence and better mental health. *J Sleep Res*. 2013;22(5):527–34.
21. Yaffe K, Nasrallah I, Hoang TD, Lauderdale DS, Knutson KL, Carnethon MR, et al. Sleep duration and white matter quality in middle-aged adults. *Sleep*. 2016;39(9):1743–7.
22. Dijk DJ, Beersma DGM, van den Hoofdakker RH. All night spectral analysis of EEG sleep in young adult and middle-aged male subjects. *Neurobiol Aging*. 1989;10(6):677–82.
23. Landolt H-P, Borbély AA. Age-dependent changes in sleep EEG topography. *Clin Neurophysiol*. 2001;112(2):369–77.
24. Landolt H-P, Dijk D-J, Achermann P, Borbély AA. Effect of age on the sleep EEG: slow-wave activity and spindle frequency activity in young and middle-aged men. *Brain Res*. 1996;738(2): 205–12.
25. Mander BA, Rao V, Lu B, Saletin JM, Lindquist JR, Ancoli-Israel S, et al. Prefrontal atrophy, disrupted NREM slow waves and impaired hippocampal-dependent memory in aging. *Nat Neurosci*. 2013;16(3):357–64.
26. Mander BA, Marks SM, Vogel JW, Rao V, Lu B, Saletin JM, et al. Beta-amyloid disrupts human NREM slow waves and related hippocampus-dependent memory consolidation. *Nat Neurosci*. 2015;18(7):1051–7.
27. Masters CL, Bateman R, Blennow K, Rowe CC, Sperling RA, Cummings JL. Alzheimer’s disease. *Nat Rev Dis Primers*. 2015;1:15056.
28. Fogel S, Vien C, Karni A, Benali H, Carrier J, Doyon J. Sleep spindles: a physiological marker of age-related changes in gray matter in brain regions supporting motor skill memory consolidation. *Neurobiology of aging*. 2017;49:154–64. **This study provides evidence that the relationship between sleep spindles and cortical grey matter is different for young and old subjects.**
29. Gaudreault PO, Gosselin N, Lafortune M, Deslauriers-Gauthier S, Martin N, Bouchard M, et al. The association between white matter and sleep spindles differs in young and older individuals. *Sleep*. 2018;41(9). **This study provides evidence that the relationship between sleep spindles and thalamocortical white matter tracts is different for young and old subjects.**
30. Sexton CE, Storsve AB, Walhovd KB, Johansen-Berg H, Fjell AM. Poor sleep quality is associated with increased cortical atrophy in community-dwelling adults. *Neurology*. 2014;83(11):967–73.
31. Branger P, Arenaza-Urquijo EM, Tomadesso C, Mezenge F, Andre C, de Flores R, et al. Relationships between sleep quality and brain volume, metabolism, and amyloid deposition in late adulthood. *Neurobiol Aging*. 2016;41:107–14.

32. Lim AS, Fleischman DA, Dawe RJ, Yu L, Arfanakis K, Buchman AS, et al. Regional neocortical gray matter structure and sleep fragmentation in older adults. *Sleep*. 2016;39(1):227–35.
33. Brown BM, Rainey-Smith SR, Villemagne VL, Weinborn M, Bucks RS, Sohrabi HR, et al. The relationship between sleep quality and brain amyloid burden. *Sleep*. 2016;39(5):1063–8.
34. Sprecher KE, Kosciak RL, Carlsson CM, Zetterberg H, Blennow K, Okonkwo OC, et al. Poor sleep is associated with CSF biomarkers of amyloid pathology in cognitively normal adults. *Neurology*. 2017;89(5):445–53.
35. Lucey BP, Hicks TJ, McLeland JS, Toedebusch CD, Boyd J, Elbert DL, et al. Effect of sleep on overnight cerebrospinal fluid amyloid beta kinetics. *Ann Neurol*. 2018;83(1):197–204. **This study provides evidence that one night of sleep deprivation results in increased levels of A β in the cerebrospinal fluid.**
36. Ju YE, Ooms S, Sutphen C, Macauley S, Zangrilli M, Jerome G, et al. Slow wave sleep disruption increases cerebrospinal fluid amyloid- β levels. *Brain*. 2017;(0):1–8. **This study provides evidence that one night of disruption to slow wave sleep specifically results in increased levels of A β in the cerebrospinal fluid.**
37. Vlassenko AG, Vaishnavi SN, Couture L, Sacco D, Shannon BJ, Mach RH, et al. Spatial correlation between brain aerobic glycolysis and amyloid- β (A β) deposition. *Proc Natl Acad Sci*. 2010;107(41):17763–7.
38. Cross NE, Lagopoulos J, Duffy SL, Cockayne NL, Hickie IB, Lewis SJ, et al. Sleep quality in healthy older people: relationship with (1) H magnetic resonance spectroscopy markers of glial and neuronal integrity. *Behav Neurosci* 2013;127(5):803–10.
39. Lim AS, Yu L, Kowgier M, Schneider JA, Buchman AS, Bennett DA. Modification of the relationship of the apolipoprotein E epsilon4 allele to the risk of Alzheimer disease and neurofibrillary tangle density by sleep. *JAMA neurology*. 2013;70(12):1544–51.
40. Lim AS, Kowgier M, Yu L, Buchman AS, Bennett DA. Sleep fragmentation and the risk of incident Alzheimer's disease and cognitive decline in older persons. *Sleep*. 2013;36(7):1027–32.
41. Lo JC, Loh KK, Zheng H, Sim SK, Chee MW. Sleep duration and age-related changes in brain structure and cognitive performance. *Sleep*. 2014;37(7):1171–8.
42. Chou YY, Lepore N, Avedissian C, Madsen SK, Parikshak N, Hua X, et al. Mapping correlations between ventricular expansion and CSF amyloid and tau biomarkers in 240 subjects with Alzheimer's disease, mild cognitive impairment and elderly controls. *NeuroImage*. 2009;46(2):394–410.
43. Porter VR, Buxton WG, Avidan AY. Sleep, cognition and dementia. *Curr Psychiatry Rep*. 2015;17(12):97.
44. Urrestarazu E, Iriarte J. Clinical management of sleep disturbances in Alzheimer's disease: current and emerging strategies. *Nat Sci Sleep*. 2016;8:21–33.
45. McKinnon A, Terpening Z, Hickie IB, Batchelor J, Grunstein R, Lewis SJ, et al. Prevalence and predictors of poor sleep quality in mild cognitive impairment. *J Geriatr Psychiatry Neurol*. 2014;27(3):204–11.
46. Naismith SL, Rogers NL, Hickie IB, Mackenzie J, Norrie LM, Lewis SJ. Sleep well, think well: sleep-wake disturbance in mild cognitive impairment. *J Geriatr Psychiatry Neurol*. 2010;23(2): 123–30.
47. Miyata S, Noda A, Iwamoto K, Kawano N, Okuda M, Ozaki N. Poor sleep quality impairs cognitive performance in older adults. *J Sleep Res*. 2013;22(5):535–41.
48. American PA. Diagnostic and statistical manual of mental disorders: DSM-5. American Psychiatric A, American Psychiatric Association DSMTF, editors. Arlington, VA: American Psychiatric Association; 2013.
49. Crowley K. Sleep and sleep disorders in older adults. *Neuropsychol Rev*. 2011;21(1):41–53.
50. Foley D, Ancoli-Israel S, Britz P, Walsh J. Sleep disturbances and chronic disease in older adults: results of the 2003 National Sleep Foundation sleep in America survey. *J Psychosom Res*. 2004;56(5):497–502.
51. Vitiello MV, Larsen LH, Moe KE. Age-related sleep change: gender and estrogen effects on the subjective-objective sleep quality relationships of healthy, noncomplaining older men and women. *J Psychosom Res*. 2004;56(5):503–10.
52. Liu X, Liu L. Sleep habits and insomnia in a sample of elderly persons in China. *Sleep*. 2005;28(12):1579–87.
53. Ohayon MM. Epidemiology of insomnia: what we know and what we still need to learn. *Sleep Med Rev*. 2002;6(2):97–111.
54. Blackwell T, Yaffe K, Laffan A, Ancoli-Israel S, Redline S, Ensrud KE, et al. Associations of objectively and subjectively measured sleep quality with subsequent cognitive decline in older community-dwelling men: the MrOS sleep study. *Sleep*. 2014;37(4):655–63.
55. Hahn EA, Wang HX, Andel R, Fratiglioni L. A change in sleep pattern may predict Alzheimer disease. *Am J Geriatr Psychiatry*. 2014;22(11):1262–71.
56. Sterniczuk R, Theou O, Rusak B, Rockwood K. Sleep disturbance is associated with incident dementia and mortality. *Curr Alzheimer Res*. 2013;10(7):767–75.
57. Virta JJ, Heikkilä K, Perola M, Koskenvuo M, Raiha I, Rinne JO, et al. Midlife sleep characteristics associated with late life cognitive function. *Sleep*. 2013;36(10):1533–41.41a.
58. de Almondes KM, Costa MV, Malloy-Diniz LF, Diniz BS. Insomnia and risk of dementia in older adults:

- systematic review and meta-analysis. *J Psychiatr Res.* 2016;77:109–15.
59. Spira AP, Chen-Edinboro LP, Wu MN, Yaffe K. Impact of sleep on the risk of cognitive decline and dementia. *Curr Opin Psychiatry.* 2014;27(6):478–83.
 60. Chen PL, Lee WJ, Sun WZ, Oyang YJ, Fuh JL. Risk of dementia in patients with insomnia and long-term use of hypnotics: a population-based retrospective cohort study. *PLoS One.* 2012;7(11):e49113.
 61. Montgomery P, Dennis J. A systematic review of non-pharmacological therapies for sleep problems in later life. *Sleep Med Rev.* 2004;8(1):47–62.
 62. Valkanova V, Ebmeier KP, Allan CL. Depression is linked to dementia in older adults. *Practitioner.* 2017;261(1800):11–5.
 63. Naismith SL, Rogers NL, Lewis SJ, Diamond K, Terpening Z, Norrie L, et al. Sleep disturbance in mild cognitive impairment: differential effects of current and remitted depression. *Acta Neuropsychiatr.* 2011;23(4):167–72.
 64. Naismith SL, Rogers NL, Lewis SJ, Terpening Z, Ip T, Diamond K, et al. Sleep disturbance relates to neuropsychological functioning in late-life depression. *J Affect Disord.* 2011;132(1–2):139–45.
 65. Winkelman JW, Benson KL, Buxton OM, Lyoo IK, Yoon S, O'Connor S, et al. Lack of hippocampal volume differences in primary insomnia and good sleeper controls: an MRI volumetric study at 3 Tesla. *Sleep Med.* 2010;11(6):576–82.
 66. Noh HJ, Joo EY, Kim ST, Yoon SM, Koo DL, Kim D, et al. The relationship between hippocampal volume and cognition in patients with chronic primary insomnia. *J Clin Neurol (Seoul, Korea).* 2012;8(2):130–8.
 67. Joo EY, Kim SH, Kim ST, Hong SB. Hippocampal volume and memory in narcoleptics with cataplexy. *Sleep Med.* 2012;13(4): 396–401.
 68. Spiegelhalder K, Regen W, Baglioni C, Kloppel S, Abdulkadir A, Hennig J, et al. Insomnia does not appear to be associated with substantial structural brain changes. *Sleep.* 2013;36(5):731–7.
 69. Winkelman JW, Plante DT, Schoerning L, Benson K, Buxton OM, O'Connor SP, et al. Increased rostral anterior cingulate cortex volume in chronic primary insomnia. *Sleep.* 2013;36(7):991–8.
 70. Koo DL, Shin JH, Lim JS, Seong JK, Joo EY. Changes in subcortical shape and cognitive function in patients with chronic insomnia. *Sleep Med.* 2017;35:23–6.
 71. Altena E, Vrenken H, Van Der Werf YD, van den Heuvel OA, Van Someren EJ. Reduced orbitofrontal and parietal gray matter in chronic insomnia: a voxel-based morphometric study. *Biol Psychiatry.* 2010;67(2):182–5.
 72. Altena E, Van Der Werf YD, Sanz-Arigita EJ, Voorn TA, Rombouts SA, Kuijter JP, et al. Prefrontal hypoactivation and recovery in insomnia. *Sleep.* 2008;31(9):1271–6.
 73. American Academy of Sleep Medicine. International classification of sleep disorders, revised: diagnostic and coding manual. Chicago, Illinois: American Academy of Sleep Medicine; 2001.
 74. Romero-Corral A, Caples SM, Lopez-Jimenez F, Somers VK. Interactions between obesity and obstructive sleep apnea: implications for treatment. *Chest.* 2010;137(3):711–9.
 75. Bixler EO, Vgontzas AN, Ten Have T, Tyson K, Kales A. Effects of age on sleep apnea in men: I. prevalence and severity. *Am J Respir Crit Care Med.* 1998;157(1):144–8.
 76. Heinzer R, Vat S, Marques-Vidal P, Marti-Soler H, Andries D, Tobback N, et al. Prevalence of sleep-disordered breathing in the general population: the HypnoLaus study. *Lancet Respir Med.* 2015;3(4):310–8.
 77. Launois SH, Pepin JL, Levy P. Sleep apnea in the elderly: a specific entity? *Sleep Med Rev.* 2007;11(2):87–97.
 78. Tufik S, Santos-Silva R, Taddei JA, Bittencourt LR. Obstructive sleep apnea syndrome in the Sao Paulo epidemiologic sleep study. *Sleep Med.* 2010;11(5):441–6.
 79. Castronovo V, Canessa N, Strambi LF, Aloia MS, Consonni M, Marelli S, et al. Brain activation changes before and after PAP treatment in obstructive sleep apnea. *Sleep.* 2009;32(9):1161–72.
 80. Kim H, Joo E, Suh S, Kim J-H, Kim ST, Hong SB. Effects of long-term treatment on brain volume in patients with obstructive sleep apnea syndrome. *Hum Brain Mapp.* 2016;37(1):395–409. **This study provides evidence that revealed the positive effects of long-term CPAP treatment on brain structure in patients with OSA.**
 81. Schenck CH, Bundlie SR, Ettinger MG, Mahowald MW. Chronic behavioral disorders of human REM sleep: a new category of parasomnia. *Sleep.* 1986;9(2):293–308.
 82. Osorio RS, Gumb T, Pirraglia E, Varga AW, Lu SE, Lim J, et al. Sleep-disordered breathing advances cognitive decline in the elderly. *Neurology.* 2015;84(19):1964–71.
 83. Boesch SM, Frauscher B, Brandauer E, Wenning GK, Hög B, Poewe W. Disturbance of rapid eye movement sleep in spinocerebellar ataxia type 2. *Mov Disord.* 2006;21(10):1751–4.
 84. Schenck CH, Mahowald MW, Kim SW, O'Connor KA, Hurwitz TD. Prominent eye movements during NREM sleep and REM sleep behavior disorder associated with fluoxetine treatment of depression and obsessive-compulsive disorder. *Sleep.* 1992;15(3):226–35.
 85. Xi Z, Luning W. REM sleep behavior disorder in a patient with pontine stroke. *Sleep Med.* 2009;10(1):143–6.

86. Fantini ML, Ferini-Strambi L, Montplaisir J. Idiopathic REM sleep behavior disorder: toward a better nosologic definition. *Neurology*. 2005;64(5):780–6.
87. Senaratna CV, Perret JL, Lodge CJ, Lowe AJ, Campbell BE, Matheson MC, et al. Prevalence of obstructive sleep apnea in the general population: a systematic review. *Sleep Med Rev*. 2017;34:70–81.
88. Edwards BA, O'Driscoll DM, Ali A, Jordan AS, Trinder J, Malhotra A. Aging and sleep: physiology and pathophysiology. *Semin Respir Crit Care Med*. 2010;31(5):618–33.
89. Marin JM, Carrizo SJ, Vicente E, Agusti AG. Long-term cardiovascular outcomes in men with obstructive sleep apnoea-hypopnoea with or without treatment with continuous positive airway pressure: an observational study. *Lancet (London, England)*. 2005;365(9464):1046–53.
90. Hla KM, Young TB, Bidwell T, Palta M, Skatrud JB, Dempsey J. Sleep apnea and hypertension. A population-based study. *Ann Intern Med*. 1994;120(5):382–8.
91. Zhang W, Liang-yi S. Obstructive sleep apnea syndrome (OSAS) and hypertension: pathogenic mechanisms and possible therapeutic approaches. *Ups J Med Sci*. 2012;117(4):370–82.
92. Arzt M, Young T, Finn L, Skatrud JB, Bradley TD. Association of Sleep-disordered Breathing and the occurrence of stroke. *Am J Respir Crit Care Med*. 2005;172(11):1447–51.
93. Redline S, Yenokyan G, Gottlieb DJ, Shahar E, O'Connor GT, Resnick HE, et al. Obstructive sleep apnea-hypopnea and incident stroke: the sleep heart health study. *Am J Respir Crit Care Med*. 2010;182(2):269–77.
94. Coughlin SR, Mawdsley L, Mugarza JA, Calverley PM, Wilding JP. Obstructive sleep apnoea is independently associated with an increased prevalence of metabolic syndrome. *Eur Heart J*. 2004;25(9):735–41.
95. Marshall NS, Wong KK, Liu PY, Cullen SR, Knuiman MW, Grunstein RR. Sleep apnea as an independent risk factor for all- cause mortality: the Busselton health study. *Sleep*. 2008;31(8): 1079–85.
96. Nieto FJ, Peppard PE, Young T, Finn L, Hla KM, Farre R. Sleep- disordered breathing and cancer mortality: results from the Wisconsin sleep cohort study. *Am J Respir Crit Care Med*. 2012;186(2):190–4.
97. Cross N, Lampit A, Pye J, Grunstein RR, Marshall N, Naismith SL. Is obstructive sleep apnoea related to neuropsychological function in healthy older adults? A systematic review and meta- analysis. *Neuropsychol Rev*. 2017;27:389–402.
98. Harada CN, Natelson Love MC, Triebel KL. Normal cognitive aging. *Clin Geriatr Med*. 2013;29(4):737–52.
99. Salthouse TA. Selective review of cognitive aging. *J Int Neuropsychol Soc*. 2010;16(5):754–60.
100. Ayalon L, Ancoli-Israel S, Klemfuss Z, Shalauta MD, Drummond SP. Increased brain activation during verbal learning in obstructive sleep apnea. *NeuroImage*. 2006;31(4):1817–25.
101. Cabeza R. Hemispheric asymmetry reduction in older adults: the HAROLD model. *Psychol Aging*. 2002;17(1):85–100.
102. Morcom AM, Good CD, Frackowiak RS, Rugg MD. Age effects on the neural correlates of successful memory encoding. *Brain*. 2003;126(Pt 1):213–29.
103. Ayalon L, Ancoli-Israel S, Drummond SP. Obstructive sleep apnea and age: a double insult to brain function? *Am J Respir Crit Care Med*. 2010;182(3):413–9.
104. Chang WP, Liu ME, Chang WC, Yang AC, Ku YC, Pai JT, et al. Sleep apnea and the risk of dementia: a population-based 5-year follow-up study in Taiwan. *PLoS One*. 2013;8(10):e78655.
105. Yaffe K, Laffan AM, Harrison SL, Redline S, Spira AP, Ensrud KE, et al. Sleep-disordered breathing, hypoxia, and risk of mild cognitive impairment and dementia in older women. *JAMA*. 2011;306(6):613–9.
106. Ancoli-Israel S, Kripke DF, Klauber MR, Mason WJ, Fell R, Kaplan O. Sleep-disordered breathing in community-dwelling elderly. *Sleep*. 1991;14(6):486–95.
107. Emamian F, Khazaie H, Tahmasian M, Leschziner GD, Morrell MJ, Hsiung G-YR, et al. The association between obstructive sleep apnea and Alzheimer's disease: a meta-analysis perspective. *Front Aging Neurosci*. 2016;8:78.
108. Braak H, Braak E. Neuropathological staging of Alzheimer- related changes. *Acta Neuropathol*. 1991;82(4):239–59.
109. Canessa N, Castronovo V, Cappa SF, Aloia MS, Marelli S, Falini A, et al. Obstructive sleep apnea: brain structural changes and neurocognitive function before and after treatment. *Am J Respir Crit Care Med*. 2011;183(10):1419–26.
110. Macey PM, Haris N, Kumar R, Thomas MA, Woo MA, Harper RM. Obstructive sleep apnea and cortical thickness in females and males. *PLoS One*. 2018;13(3):e0193854.
111. Morrell MJ, McRobbie DW, Quest RA, Cummin AR, Ghiassi R, Corfield DR. Changes in brain morphology associated with obstructive sleep apnea. *Sleep Med*. 2003;4(5):451–4.
112. Torelli F, Moscufo N, Garreffa G, Placidi F, Romigi A, Zannino S, et al. Cognitive profile and brain morphological changes in obstructive sleep apnea. *NeuroImage*. 2011;54(2):787–93.

113. Weng HH, Tsai YH, Chen CF, Lin YC, Yang CT, Tsai YH, et al. Mapping gray matter reductions in obstructive sleep apnea: an activation likelihood estimation meta-analysis. *Sleep*. 2014;37(1): 167–75.
114. Yaouhi K, Bertran F, Clochon P, Mezenge F, Denise P, Foret J, et al. A combined neuropsychological and brain imaging study of obstructive sleep apnea. *J Sleep Res*. 2009;18(1):36–48.
115. Baril AA, Gagnon K, Brayet P, Montplaisir J, De Beaumont L, Carrier J, et al. Gray matter hypertrophy and thickening with obstructive sleep apnea in middle-aged and older adults. *Am J Respir Crit Care Med*. 2017;195(11):1509–18. This study provides evidence that OSA is associated with increased cortical thickness in healthy and older middle-aged adults, suggestive of reactive or maladaptive processes.
116. Celle S, Peyron R, Faillenot I, Pichot V, Alabdullah M, Gaspoz JM, et al. Undiagnosed sleep-related breathing disorders are associated with focal brainstem atrophy in the elderly. *Hum Brain Mapp*. 2009;30(7):2090–7.
117. Cross NE, Memarian N, Duffy SL, Paquola C, LaMonica H, D'Rozario A, et al. Structural brain correlates of obstructive sleep apnoea in older adults at risk for dementia. *Eur Respir J*. 2018;52(1). **This study provides evidence that OSA is associated with increased thickness in some cortical areas, and decreased thickness in the temporal cortices, in older middle-aged adults with subjective and objective cognitive impairment.**
118. Boucetta S, Salimi A, Dadar M, Jones BE, Collins DL, Dang-Vu TT. Structural brain alterations associated with rapid eye movement sleep behavior disorder in Parkinson's disease. *Sci Report*. 2016;6:26782. **This study provides evidence of extensive structural abnormalities associated with RBD in Parkinson's disease, which prominently involved volume decreases in the pontomesencephalic tegmentum, supporting a consistent loss of neurons in this region with RBD.**
119. Duffy SL, Lagopoulos J, Terpening Z, Lewis SJ, Grunstein R, Mowszowski L, et al. Association of anterior cingulate glutathione with sleep apnea in older adults at-risk for dementia. *Sleep*. 2016;39(4):899–906.
120. Rosenzweig I, Williams SC, Morrell MJ. The impact of sleep and hypoxia on the brain: potential mechanisms for the effects of obstructive sleep apnea. *Curr Opin Pulm Med*. 2014;20(6):565–71.
121. Rostanski SK, Zimmerman ME, Schupf N, Manly JJ, Westwood AJ, Brickman AM, et al. Sleep disordered breathing and white matter hyperintensities in community-dwelling elders. *Sleep*. 2016;39(4):785–91.
122. Gomez-Choco MJ, Iranzo A, Blanco Y, Graus F, Santamaria J, Saiz A. Prevalence of restless legs syndrome and REM sleep behavior disorder in multiple sclerosis. *Multiple sclerosis*. Houndmills, Basingstoke, England. 2007;13(6):805–8.
123. Plazzi G, Corsini R, Provini F, Pierangeli G, Martinelli P, Montagna P, et al. REM sleep behavior disorders in multiple system atrophy. *Neurology*. 1997;48(4):1094–7.
124. Zhang X, Sun X, Wang J, Tang L, Xie A. Prevalence of rapid eye movement sleep behavior disorder (RBD) in Parkinson's disease: a meta and meta-regression analysis. *Neurol Sci*. 2017;38(1):163–70.
125. Boeve BF, Silber MH, Ferman TJ, Kokmen E, Smith GE, Ivnik RJ, et al. REM sleep behavior disorder and degenerative dementia: an association likely reflecting Lewy body disease. *Neurology*. 1998;51(2):363–70.
126. McKeith IG, Boeve BF, Dickson DW, Halliday G, Taylor JP, Weintraub D, et al. Diagnosis and management of dementia with Lewy bodies: fourth consensus report of the DLB consortium. *Neurology*. 2017;89(1):88–100.
127. Postuma RB, Gagnon JF, Montplaisir JY. REM sleep behavior disorder: from dreams to neurodegeneration. *Neurobiol Dis*. 2012;46(3):553–8.
128. Boot BP, Boeve BF, Roberts RO, Ferman TJ, Geda YE, Pankratz VS, et al. Probable rapid eye movement sleep behavior disorder increases risk for mild cognitive impairment and Parkinson disease: a population-based study. *Ann Neurol*. 2012;71(1):49–56.
129. Postuma RB, Gagnon JF, Vendette M, Fantini ML, Massicotte- Marquez J, Montplaisir J. Quantifying the risk of neurodegenerative disease in idiopathic REM sleep behavior disorder. *Neurology*. 2009;72(15):1296–300.
130. Iranzo A, Tolosa E, Gelpi E, Molinuevo JL, Valldeoriola F, Serradell M, et al. Neurodegenerative disease status and post-mortem pathology in idiopathic rapid-eye-movement sleep behaviour disorder: an observational cohort study. *Lancet Neurol*. 2013;12(5):443–53.
131. Schenck CH, Boeve BF, Mahowald MW. Delayed emergence of a parkinsonian disorder or dementia in 81% of older men initially diagnosed with idiopathic rapid eye movement sleep behavior disorder: a 16-year update on a previously reported series. *Sleep Med*. 2013;14(8):744–8.
132. Boeve BF, Silber MH, Ferman TJ, Lin SC, Benarroch EE, Schmeichel AM, et al. Clinicopathologic correlations in 172 cases of rapid eye movement sleep behavior disorder with or without a coexisting neurologic disorder. *Sleep Med*. 2013;14(8):754–62.
133. Vilas D, Iranzo A, Tolosa E, Aldecoa I, Berenguer J, Vilaseca I, et al. Assessment of alpha-synuclein in submandibular glands of patients with idiopathic rapid

- eye-movement sleep behaviour disorder: a case-control study. *Lancet Neurol.* 2016;15(7):708–18.
134. Postuma RB, Gagnon JF, Montplaisir J. Clinical prediction of Parkinson's disease: planning for the age of neuroprotection. *J Neurol Neurosurg Psychiatry.* 2010;81(9):1008–13.
135. Siegel JM, Tobler I. Mammalian sleep. *Principles and Practice of Sleep Medicine.* 42005. p. 91–100.
136. Weber F, Chung S, Beier KT, Xu M, Luo L, Dan Y. Control of REM sleep by ventral medulla GABAergic neurons. *Nature.* 2015;526(7573):435–8.
137. Magoun HW, Rhines R. An inhibitory mechanism in the bulbar reticular formation. *J Neurophysiol.* 1946;9:165–71.
138. Schenkel E, Siegel JM. REM sleep without atonia after lesions of the medial medulla. *Neurosci Lett.* 1989;98(2):159–65.
139. Knudsen S, Gammeltoft S, Jennum PJ. Rapid eye movement sleep behaviour disorder in patients with narcolepsy is associated with hypocretin-1 deficiency. *Brain J Neurol.* 2010;133(Pt 2):568–79.
140. Kajimura N, Uchiyama M, Takayama Y, Uchida S, Uema T, Kato M, et al. Activity of midbrain reticular formation and neocortex during the progression of human non-rapid eye movement sleep. *J Neurosci.* 1999;19(22):10065–73.
141. Maquet P, Peters J, Aerts J, Delfiore G, Degueldre C, Luxen A, et al. Functional neuroanatomy of human rapid-eye-movement sleep and dreaming. *Nature.* 1996;383(6596):163–6.
142. Hendricks JC, Morrison AR, Mann GL. Different behaviors during paradoxical sleep without atonia depend on pontine lesion site. *Brain Res.* 1982;239(1):81–105.
143. Sakai K, Sastre JP, Salvert D, Touret M, Tohyama M, Jouvet M. Tegmentoreticular projections with special reference to the muscular atonia during paradoxical sleep in the cat: an HRP study. *Brain Res.* 1979;176(2):233–54.
144. Scherfler C, Frauscher B, Schocke M, Iranzo A, Gschliesser V, Seppi K, et al. White and gray matter abnormalities in idiopathic rapid eye movement sleep behavior disorder: a diffusion-tensor imaging and voxel-based morphometry study. *Ann Neurol.* 2011;69(2):400–7.
145. Unger MM, Belke M, Menzler K, Heverhagen JT, Keil B, Stiasny-Kolster K, et al. Diffusion tensor imaging in idiopathic REM sleep behavior disorder reveals microstructural changes in the brainstem, substantia nigra, olfactory region, and other brain regions. *Sleep.* 2010;33(6):767–73.
146. Hanyu H, Inoue Y, Sakurai H, Kanetaka H, Nakamura M, Miyamoto T, et al. Voxel-based magnetic resonance imaging study of structural brain changes in patients with idiopathic REM sleep behavior disorder. *Parkinsonism Relat Disord.* 2012;18(2):136–9.
147. Rahayel S, Montplaisir J, Monchi O, Bedetti C, Postuma RB, Brambati S, et al. Patterns of cortical thinning in idiopathic rapid eye movement sleep behavior disorder. *Mov Disord.* 2015;30(5): 680–7.
148. Ford AH, Duncan GW, Firbank MJ, Yamall AJ, Khoo TK, Burn DJ, et al. Rapid eye movement sleep behavior disorder in Parkinson's disease: magnetic resonance imaging study. *Mov Disord.* 2013;28(6):832–6.
149. Garcia-Lorenzo D, Longo-Dos Santos C, Ewencyk C, Leu-Semenescu S, Gallea C, Quattrocchi G, et al. The coeruleus/ subcoeruleus complex in rapid eye movement sleep behaviour disorders in Parkinson's disease. *Brain J Neurol.* 2013;136(Pt 7): 2120–9.
150. Salsone M, Cerasa A, Arabia G, Morelli M, Gambardella A, Mumoli L, et al. Reduced thalamic volume in Parkinson disease with REM sleep behavior disorder: volumetric study. *Parkinsonism Relat Disord.* 2014;20(9):1004–8.
151. Dauvilliers Y, Boudousq V, Lopez R, Gabelle A, De Cock VC, Bayard S, et al. Increased perfusion in supplementary motor area during a REM sleep behaviour episode. *Sleep Med.* 2011;12(5):531–2.
152. Kim YK, Yoon IY, Kim JM, Jeong SH, Kim KW, Shin YK, et al. The implication of nigrostriatal dopaminergic degeneration in the pathogenesis of REM sleep behavior disorder. *Eur J Neurol.* 2010;17(3):487–92.
153. Eiseensehr I, Linke R, Noachtar S, Schwarz J, Gildehaus FJ, Tatsch K. Reduced striatal dopamine transporters in idiopathic rapid eye movement sleep behaviour disorder. Comparison with Parkinson's disease and controls. *Brain.* 2000;123(Pt 6):1155–60.
154. Eiseensehr I, Linke R, Tatsch K, Kharraz B, Gildehaus JF, Wetter CT, et al. Increased muscle activity during rapid eye movement sleep correlates with decrease of striatal presynaptic dopamine transporters. IPT and IBZM SPECT imaging in subclinical and clinically manifest idiopathic REM sleep behavior disorder, Parkinson's disease, and controls. *Sleep.* 2003;26(5):507–12.
155. Iranzo A, Lomena F, Stockner H, Valldeoriola F, Vilaseca I, Salamero M, et al. Decreased striatal dopamine transporter uptake and substantia nigra hyperechogenicity as risk markers of synucleinopathy in patients with idiopathic rapid-eye-movement sleep behaviour disorder: a prospective study [corrected]. *Lancet Neurol.* 2010;9(11):1070–7.
156. Stiasny-Kolster K, Doerr Y, Moller JC, Hoffken H, Behr TM, Oertel WH, et al. Combination of 'idiopathic' REM sleep behaviour disorder and olfactory dysfunction as possible indicator for alpha-synucleinopathy demonstrated by dopamine transporter FP- CIT-SPECT. *Brain.* 2005;128(Pt 1):126–37.

157. Unger MM, Moller JC, Stiasny-Kolster K, Mankel K, Berg D, Walter U, et al. Assessment of idiopathic rapid-eye-movement sleep behavior disorder by transcranial sonography, olfactory function test, and FP-CIT-SPECT. *Mov Disord*. 2008;23(4):596–9.
158. Rolinski M, Griffanti L, Piccini P, Roussakis AA, Szewczyk-Krolikowski K, Menke RA, et al. Basal ganglia dysfunction in idiopathic REM sleep behaviour disorder parallels that in early Parkinson's disease. *Brain*. 2016;139(Pt 8):2224–34.
159. Dang-Vu TT, Gagnon JF, Vendette M, Soucy JP, Postuma RB, Montplaisir J. Hippocampal perfusion predicts impending neuro-degeneration in REM sleep behavior disorder. *Neurology*. 2012;79(24):2302–6.
160. Yao C, Fereshtehnejad SM, Dawson BK, Pelletier A, Gan-Or Z, Gagnon JF, et al. Longstanding disease-free survival in idiopathic REM sleep behavior disorder: is neurodegeneration inevitable?, *Parkinsonism Relat Disord*, 2018;54:99–102. **This study provides evidence that despite differences in phenoconversion rates, almost all individuals with iRBD appear to have underlying neurodegeneration.**
161. Alhola P, Polo-Kantola P. Sleep deprivation: impact on cognitive performance. *Neuropsychiatr Dis Treat*. 2007;3(5):553–67.
162. Chee MW, Chuah LY. Functional neuroimaging insights into how sleep and sleep deprivation affect memory and cognition. *Curr Opin Neurol*. 2008;21(4):417–23.
163. Goel N, Rao H, Durmer JS, Dinges DF. Neurocognitive consequences of sleep deprivation. *Semin Neurol*. 2009;29(4):320–39.
164. Wickwire EM, Williams SG, Roth T, Capaldi VF, Jaffe M, Moline M, et al. Sleep, sleep disorders, and mild traumatic brain injury. What we know and what we need to know: findings from a National Working Group. *Neurotherapeutics*. 2016;13(2):403–17.
165. Duss SB, Seiler A, Schmidt MH, Pace M, Adamantidis A, Müri RM, et al. The role of sleep in recovery following ischemic stroke: a review of human and animal data. *Neurobiol Sleep Circadian Rhythms*. 2017;2:94–105.
166. Kay DB, Dzierzewski JM. Sleep in the context of healthy aging and psychiatric syndromes. *Sleep Med Clin*. 2015;10(1):11–5.
167. Dauvilliers Y. Insomnia in patients with neurodegenerative conditions. *Sleep Med*. 8 Suppl 4:S27–34.
168. Haba-Rubio J, Frauscher B, Marques-Vidal P, Toriel J, Tobback N, Andries D, Preisig M, Vollenweider P, Postuma R, Heinzer R. Prevalence and Determinants of REM Sleep Behavior Disorder in the General Population. *Sleep*. 2017;zsx197.
169. Chiu HF, Wing YK, Lam LC, Li SW, Lum CM, Leung T, Ho CK. Sleep-related injury in the elderly—an epidemiological study in Hong Kong. *Sleep*. 2000;23(4):513–7.

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