cortex 65 (2015) 128–138

Available online at www.sciencedirect.com

ScienceDirect

Journal homepage: www.elsevier.com/locate/cortex

Clinical neuroanatomy

Subcortical volumetric changes across the adult lifespan: Subregional thalamic atrophy accounts for age-related sensorimotor performance declines

Leen Serbruyns [a], Inge Leunissen [a], Toon Huysmans [b], Koen Cuypers [a,c], Raf L. Meesen [a,c], Peter van Ruitenbeek [a], Jan Sijbers [b] and Stephan P. Swinnen [a,d,]*

[a] *Motor Control Laboratory, Movement Control and Neuroplasticity Research Group, Biomedical Sciences Group, Department of Kinesiology, KU Leuven, Belgium*

[b] *Vision Lab, Department of Physics, University of Antwerp, Belgium*

[c] *REVAL Rehabilitation Research Centre, Biomedical Research Institute, Faculty of Medicine and Life Sciences, Hasselt University, Diepenbeek, Belgium*

[d] *Leuven Research Institute for Neuroscience & Disease (LIND), KU Leuven, Belgium*

ARTICLE INFO

Article history:
Received 19 August 2014
Reviewed 16 October 2014
Revised 28 November 2014
Accepted 5 January 2015
Action editor Marco Catani
Published online 26 January 2015

Keywords:
Aging
Coordination
Thalamus
Shape
Mediation

ABSTRACT

Even though declines in sensorimotor performance during healthy aging have been documented extensively, its underlying neural mechanisms remain unclear. Here, we explored whether age-related subcortical atrophy plays a role in sensorimotor performance declines, and particularly during bimanual manipulative performance (Purdue Pegboard Test). The thalamus, putamen, caudate and pallidum of 91 participants across the adult lifespan (ages 20–79 years) were automatically segmented. In addition to studying age-related changes in the global volume of each subcortical structure, local deformations within these structures, indicative of subregional volume changes, were assessed by means of recently developed shape analyses. Results showed widespread age-related global and subregional atrophy, as well as some notable subregional expansion. Even though global atrophy failed to explain the observed performance declines with aging, shape analyses indicated that atrophy in left and right thalamic subregions, specifically subserving connectivity with the premotor, primary motor and somatosensory cortical areas, mediated the relation between aging and performance decline. It is concluded that subregional volume assessment by means of shape analyses offers a sensitive tool with high anatomical resolution in the search for specific age-related associations between brain structure and behavior.

* *Corresponding author*. Motor Control Laboratory, Movement Control and Neuroplasticity Research Group, Biomedical Sciences Group, Department of Kinesiology, KU Leuven, Tervuursevest 101, B-3001 Heverlee, Belgium.

E-mail address: Stephan.Swinnen@faber.kuleuven.be (S.P. Swinnen).

http://dx.doi.org/10.1016/j.cortex.2015.01.003
0010-9452/

1. Introduction

Bimanual skills are ubiquitous during many daily life activities, such as getting dressed or eating. During healthy aging, these skills have been shown to deteriorate (Bernard & Seidler, 2012; Fling & Seidler, 2012; Marneweck, Loftus, & Hammond, 2011; Serbruyns et al., 2013; Sullivan et al., 2001; Swinnen et al., 1998). However, fundamental knowledge of the neural mechanisms behind these age-related declines is rather limited.

Recent aging studies have focused on activity of the cerebral cortex, and have made some progress in determining the role of age-related functional brain changes in bimanual performance declines (Goble et al., 2010; Heitger et al., 2013; Kiyama, Kunimi, Iidaka, & Nakai, 2014; Solesio-Jofre et al., 2014). Other aging studies have demonstrated a significant role of microstructural changes in white matter structures and particularly the corpus callosum (Fling et al., 2011; Gooijers & Swinnen, 2014; Serbruyns et al., 2013; Sullivan et al., 2001), the largest white matter tract connecting interhemispheric cortical regions (Jarbo, Verstynen, & Schneider, 2012). However, to the best of our knowledge, the role of subcortical changes in bimanual performance declines in healthy aging has not been investigated. The importance of subcortical structures for bimanual coordination is indirectly implied by several functional magnetic resonance imaging (fMRI) studies in healthy young adults showing that bimanual coordination relies on a distributed network, including subcortical structures (Debaere, Wenderoth, Sunaert, Van Hecke, & Swinnen, 2003, 2004a, 2004b; Kraft et al., 2007; Ng, Sowman, Brock, & Johnson, 2013; Puttemans, Wenderoth, & Swinnen, 2005; Van Der Graaf, De Jong, Maguire, Meiners, & Leenders, 2004). Furthermore, patients with subcortical impairments, such as patients with Parkinson's disease or with subcortical lesions, have been shown to experience difficulties with bimanual performance (Haaxma et al., 1995; Johnson et al., 1998; Kuoppamaki et al., 2005; Mochizuki-Kawai et al., 2004; Serrien, Steyvers, Debaere, Stelmach, & Swinnen, 2000; Swinnen, Steyvers, Van Den Bergh, & Stelmach, 2000; Verschueren, Swinnen, Dom, & De Weerdt, 1997). Based on previous indications that subcortical gray matter structures undergo age-related degenerative changes (Cherubini, Peran, Caltagirone, Sabatini, & Spalletta, 2009; Fjell et al., 2013; Goodro, Sameti, Patenaude, & Fein, 2012; Gunning-Dixon, Head, McQuain, Acker, & Raz, 1998; Hughes et al., 2012; Inano et al., 2013; Jancke, Merillat, Liem, & Hanggi, 2014; Jiang et al., 2014; Li et al., 2014; Long et al., 2012; Walhovd et al., 2005, 2011), investigating the relationship between these changes and bimanual functioning may help in unraveling the neural basis of age-related bimanual performance declines.

The main subcortical structures involved in bimanual coordination are the thalamus (Debaere et al., 2003, 2004a, 2004b; Ng et al., 2013), putamen (Debaere et al., 2003, 2004b; Ng et al., 2013; Van Der Graaf et al., 2004), caudate (Debaere et al., 2003; Ng et al., 2013) and pallidum (Debaere, Wenderoth, Sunaert, Van Hecke, & Swinnen, 2004a, 2004b; Ng et al., 2013; Van Der Graaf et al., 2004). These structures are part of the cortico-subcortical motor circuit, receiving inputs from the cerebral cortex via cortico-striatal inputs and ultimately projecting back to distinct zones of the cortex through thalamocortical pathways (Alexander, Delong, & Strick, 1986; Hoover & Strick, 1993). Anatomical connectivity information, derived from diffusion tensor imaging (DTI) and probabilistic tractography, has shown that these subcortical projections are topographically organized, i.e., clustered according to function, congruent with primate data. In this way, each of these subcortical structures can be parcellated into functionally distinct subregions (Behrens et al., 2003; Tziortzi et al., 2014; Zhang, Snyder, Shimony, Fox, & Raichle, 2010). Recently, a new method has been proposed that, in addition to the assessment of total volume per subcortical structure (i.e., 'global' volumes), allows for accurate and robust localization of volumetric changes within such distinct subregions of each of these structures (i.e., 'subregional volume') by means of shape analyses in T1-weigthed MRI images (Patenaude, Smith, Kennedy, & Jenkinson, 2011). That is, it allows for the detection of shape differences in terms of inward or outward deformation, which implies local volume decreases (i.e., subregional atrophy) or local volume increases (i.e., subregional expansion), respectively. Previous research from our group in traumatic brain injury patients and healthy controls has shown that these subregional volumetric measures provide greater sensitivity as compared to global volumetric measures in detecting correlations with behavioral measures (Leunissen et al., 2014). Moreover, shape analyses enable purely local volumetric analyses, which are based directly on the location of the structures' boundaries and thus are not dependent on tissue-type classification or smoothing extents (Patenaude et al., 2011). As such, shape analyses have the potential to be more sensitive to local volumetric changes as compared to more conventional methods. This idea is further strengthened by two very recent studies detecting gray matter subcortical differences between patients and healthy controls using shape analyses, but not (Menke et al., 2014) or to a lesser extent (Kim, Kim, Seo, Suh, & Koh, 2013) using voxel-based morphometry. Furthermore, shape analyses have already been employed successfully to detect atrophy with increasing age in subregions of the bilateral thalamus (Hughes et al., 2012; Jiang et al., 2014), bilateral putamen, and left pallidum (Jiang et al., 2014). In view of the observed functional topography within subcortical structures, shape analyses offer great potential for the identification of age-related atrophy in subcortical subregions potentially mediating sensorimotor performance declines.

In the current study, we investigated the role of global and subregional subcortical volumetric changes in age-related bimanual performance declines across the adult lifespan. Bilateral thalamus, putamen, caudate and pallidum were selected as structures of interest. Our hypotheses were threefold: (1) bimanual performance will decline with increasing age, (2) the selected subcortical structures will show atrophy with increasing age, and (3) atrophy of subregions connected with cortical regions involved in motor coordination will account for age-related bimanual performance declines.

To the best of our knowledge, this is the first study offering a detailed overview of age-related global and in particular subregional volumetric changes in multiple subcortical structures across the whole adult lifespan, as well as in delineating their role in sensorimotor performance declines.