

Dual Task Interference in Parkinson's Disease

Tao Wu, MD¹ and Mark Hallett, MD²

1. Associate Professor of Neurobiology, Department of Neurobiology, Beijing Institute of Geriatrics, Xuanwu Hospital, Capital Medical University, Beijing;

2. Chief, Human Motor Control Section, Medical Neurology Branch, National Institute of Neurological Disorders and Stroke, National Institutes of Health

Abstract

Performing two tasks simultaneously (dual task performance) is a frequent activity in human life. Patients with Parkinson's disease (PD) commonly have more difficulty in performing dual tasks than healthy people. To date, research on the mechanisms of dual task interference in PD remains sparse. A recent study by Wu and Hallett in 2008 investigated the central neural correlates of dual task interference in PD, and demonstrated that dual task interference in PD is due to multiple reasons. First, the limitation of capacity of attentional resources is exceeded; second, PD patients perform tasks less automatically compared with normal subjects; and third, the central executive may be defective. However, our knowledge of this phenomenon is still far from complete and needs further investigation.

Keywords

Parkinson's disease, dual task, functional magnetic resonance imaging (fMRI), brain activity, attentional resource, automaticity, central supervisor

Disclosure: The authors have no conflicts of interest to disclose.

Received: January 7, 2009 **Accepted:** July 13, 2009 **DOI:** 10.17925/USN.2009.05.01.30

Correspondence: Mark Hallett, MD, Bldg 10, Rm 7D37, 10 Center Drive MSC 1428, Bethesda, Maryland 20892-1428. E: hallettm@ninds.nih.gov

Performing two tasks simultaneously (dual task performance) is a frequent activity in human life. However, performing dual tasks can be difficult. When people attempt to perform dual tasks, performance is generally impaired, manifested by increased errors or reaction times compared with when the tasks are performed individually. Such a deterioration of performance is defined as dual task interference.¹

The underlying mechanism of dual task interference is still unclear. It has been described as a competition for attentional resources,² or competition for information-processing mechanisms.³ Three of the most influential explanations are capacity-sharing, bottlenecks, and cross-talk.¹ These are 'attentional' models, with the term 'attentional' referring to the focus of mental activity on a task. The capacity-sharing model is based on the assumption that attentional resources are limited. When people perform two tasks simultaneously, resources must be divided between the tasks. How attention is divided between the two tasks relies on several factors, including task complexity, familiarity, and importance. According to this model, dual task interference occurs only if the available resource capacity is exceeded, resulting in a decline in performance on one or both of the tasks.²⁻⁴ The bottleneck theory refers to the idea that certain critical mental operations must be carried out sequentially. A bottleneck arises when two tasks require a critical mental operation at the same time-point.⁵ In contrast, the cross-talk model assumes that task similarity reduces dual task interference because the use of the same pathway increases the efficiency of processing by using less attentional resource capacity.⁴⁻⁷

Patients with Parkinson's disease (PD) commonly have difficulties in performing movements. This problem becomes more prominent during their performance of complex movements, including dual tasks. Schwab et al.⁸ described that PD patients have particular difficulty executing two motor tasks simultaneously. This problem is more obvious when patients perform different motor acts with each hand. For example, a patient may be unable to draw a triangle with his or her dominant hand while squeezing a bulb with the other hand, or he or she may be very slow in performing simultaneous tasks, such as flexing the elbow and pinching the thumb and index finger at the same time. Benecke et al.^{9,10} found that when PD patients were asked to perform rapid elbow movements combined with a simultaneous or sequential hand movement, they showed a marked slowing of movement greater than that seen in each task individually. By contrast, there was no decrement of performance in normal subjects when two tasks were combined. This deficiency correlated better with clinical measures of bradykinesia, and improved more impressively after administration of L-Dopa than the slowness in each component movement.¹¹ Similar observations have been described in several subsequent studies.¹²⁻¹⁴

The problem of performing two tasks simultaneously in PD patients is not confined to motor tasks. It can also be observed in cognitive tasks or combined cognitive and motor tasks.^{15,16} For example, Brown and Marsden found that PD patients had an increase in reaction time on the Stroop task when performing a resource-demanding secondary task simultaneously.¹⁵ These observations suggest that the difficulty of performing two tasks at the same time in PD patients is not a purely

motor problem. Impaired dual task performance was also reported during gait in PD patients.^{17,18} Dual task interference can also be observed in postural control when PD patients perform a secondary task simultaneously.¹⁹⁻²² For example, Morris and colleagues demonstrated that a concomitant verbal-cognitive task significantly deteriorated postural stability in PD.¹⁹ Ashburn and co-workers found that a greater postural sway was present in PD patients who were fallers while completing a distracting cognitive task.^{20,21}

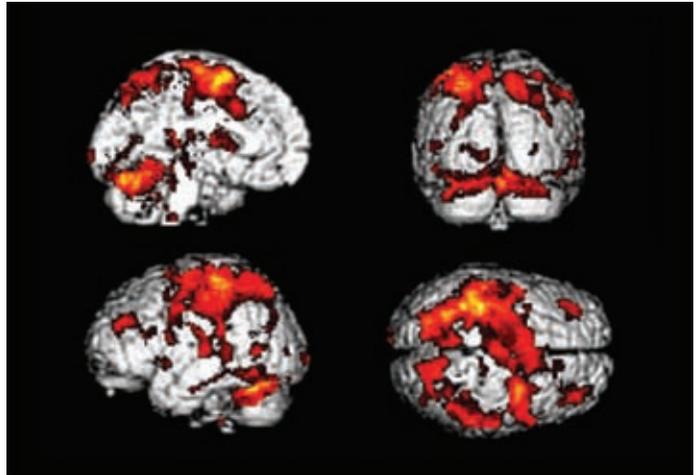
An adequate understanding of the deficiency of PD patients in performing two tasks simultaneously is important. It may help in the development of optimal therapy strategies. However, to date, research on the mechanisms of dual task interference in PD remains sparse. It has been assumed that PD patients either have a limited attentional resource that interferes with their ability to execute more than one task at the same time, or that they have difficulty in switching this resource between tasks.^{15,23} An alternative explanation is that the attentional resource is relatively intact but the patients perform the tasks less automatically than normal subjects. Patients may use more resources for each single task to compensate for deficient function of the basal ganglia. Each task would consume more of the attentional resource, leading to difficulties in performing two tasks at the same time. It has also been suggested that difficulty in performing a dual motor task in PD patients may be caused by sensorimotor interference between motor programs,²⁴ whereas difficulty in performing a dual cognitive task may be caused by a central executive deficit.²⁵ In addition, as using various secondary tasks can have different influences on performance of dual tasks,²⁶ it has been suggested that various dual tasks may not share the same neural mechanisms.

A recent study from our group has clarified some of these issues concerning dual task interference in PD, such as to what degree the ability of dual task performance in PD patients is defective, whether practice can improve their performance of dual tasks, and, importantly, the central neural correlates of the problem in PD.²⁷ To answer these questions, we asked PD patients to perform some dual tasks combined

An adequate understanding of the deficiency of Parkinson's disease patients in performing two tasks simultaneously is important. It may help in the development of optimal therapy strategies.

with sequential right-hand movements and different secondary tasks, including a visual letter counting task, or a left-hand tapping task. The dual tasks were set up with different levels of complexity. After extensive training, most healthy subjects could perform all dual tasks correctly. By contrast, most patients could perform only the simpler dual tasks with high accuracy. This finding demonstrated that PD patients have more difficulty than healthy people in performing dual tasks. However, they can still execute some relatively simple dual tasks correctly after extensive training. We found no difference when patients

Figure 1: Brain Regions Activated While Performing Dual Task of Sequential Movement/Visual Letter Counting After Training in Patients with Parkinson's Disease



Results were thresholded at $p < 0.05$ (with multiple comparison correction) and rendered over a standard anatomical brain.

Source: Wu and Hallett, J Neurol Neurosurg Psychiatry, 2008;79:760-66.

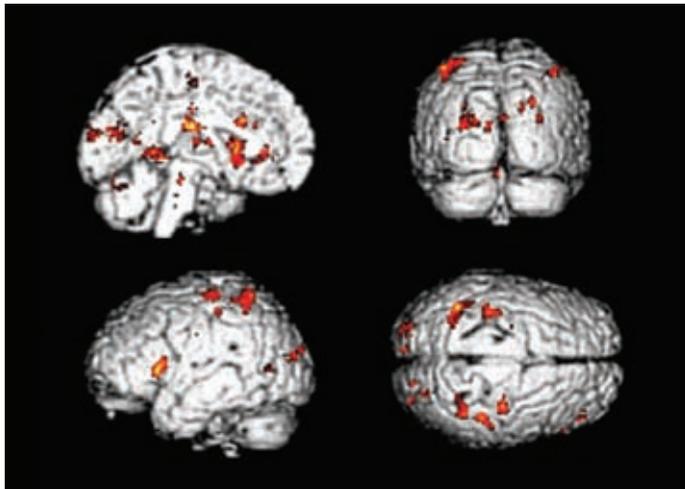
performed a motor or cognitive dual task together with a primary motor task, which suggests that various secondary tasks may not necessarily induce different dual task performance in PD patients.^{22,24}

Normal subjects can perform sequential movements automatically after training, and remaining brain resources are sufficient to maintain the performance of a secondary task. By contrast, PD patients have more difficulty in performing movements automatically and require more brain processing resource to compensate for basal ganglia dysfunction to perform automatic movements.²⁸ Therefore, even if attentional resources may be relatively intact, PD patients will still have difficulties performing two tasks at the same time.

Using functional MRI (fMRI), our study found that both before and after training, for both normal subjects and patients, performance of a dual task of sequential movement/letter counting was associated with activations of the left primary sensorimotor cortex (SM1), bilateral premotor area (PMA), bilateral parietal cortex, bilateral precuneus, bilateral dorsal lateral prefrontal cortex (DLPFC), supplementary motor area (SMA), cingulate motor area (CMA), basal ganglia, bilateral cerebellum, and occipital cortex (see Figure 1). Brain regions activated while performing the dual task of sequential movement/tapping were similar, but with activity in the right SM1 instead of the occipital cortex. The observation that the pattern of brain activity was similar in different dual tasks suggests that various dual tasks may not necessarily employ different neural mechanisms.

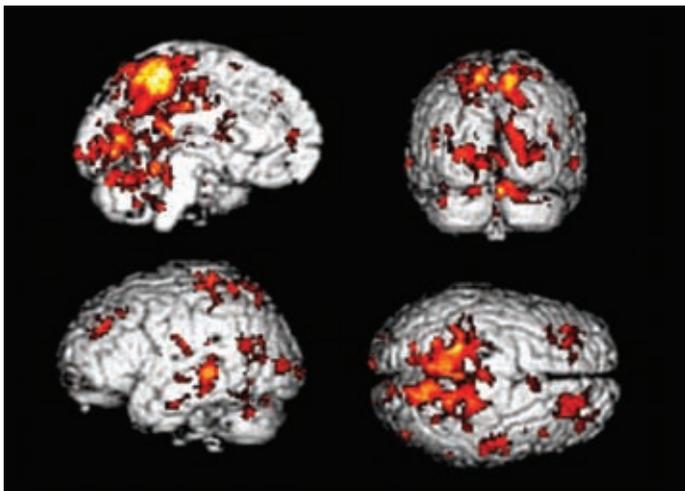
After training, in patients bilateral parietal cortex and PMA were less activated compared with before training (see Figure 2). In normal subjects, there was less activation in the bilateral PMA, bilateral parietal cortex, and pre-SMA. There was less activity after training compared with before training (see Figure 2), which indicates that training improves performance and makes brain activity more efficient in executing dual tasks. This observation supports the presumption that diminished dual task interference may correlate with reduced resource

Figure 2: Brain Areas More Activated at the Before-training Stage than at the After-training Stage When Performing Dual Task of Sequential Movement/ Visual Letter Counting in Parkinson's Disease Patients



Results were thresholded at $p < 0.05$ (corrected) and rendered over a standard anatomical brain.
Source: Wu and Hallett, *J Neurol Neurosurg Psychiatry*, 2008;79:760–66.

Figure 3. Brain Areas More Activated in Parkinson's Disease Patients than in Normal Subjects During Performance of Dual Task of Sequential Movement/ Visual Letter Counting at the After-training Stage



Results were thresholded at $p < 0.05$ (corrected) and rendered over a standard anatomical brain.
Source: Wu and Hallett, *J Neurol Neurosurg Psychiatry*, 2008;79:760–66.

demands of the tasks. Dual task interference is always substantial at a low level of practice; however, after extensive practice it is reduced and even disappears.^{29,30} After practice, brain capacity was no longer exceeded in normal subjects, and they could perform the dual tasks accurately. By contrast, although not behaviorally different, PD patients required greater activation than normal subjects to perform the simpler dual tasks. Patients had greater activation in the bilateral DLPFC, middle frontal gyrus, bilateral PMA, bilateral parietal cortex, bilateral precuneus, bilateral temporal lobe, occipital lobe, bilateral cerebellum, thalamus,

and cingulate gyrus compared with normal subjects when performing dual tasks (see *Figure 3*). No area was more activated in normal subjects than in patients. Several of these areas, such as the prefrontal cortex,^{31–34} middle frontal gyrus,^{31,34,35} parietal cortex,^{34–36} temporal lobe,³⁶ and cerebellum,³⁵ have been shown to be associated with dual task performance. The prefrontal cortex, especially the DLPFC, is important in attention³⁷ and performance monitoring,³⁸ and is involved in the allocation and coordination of attentional resources.³¹ The parietal cortex is involved in attention, working memory, and executive processes.^{39,40} The PMA and cerebellum are associated with temporal organization or control.^{41,42} More activity in these regions in patients correlating with their poorer performance further indicates that the difficulty of PD patients in performing the dual task is due to a requirement for more brain resources. Possibly, for the more complex dual task, the limitation of capacity was exceeded in most patients. Thus, they could not perform the more complex dual task correctly, and dual task interference still existed.

It has been observed that dual task interference is associated with overlapping cortical activation; the larger volume of overlap is accompanied by greater interference.⁴³ The study that showed this also found that brain regions activated by sequential movements overlapped with the secondary task in several locations. However, no difference in the overlapping areas—either between the groups or between the before- and after-training stages within each group—was observed, which suggests that the decreased dual task interference may not be due to less overlapping of the two single tasks. Dual tasks could be executed without significant interference even when the two tasks activated overlapped brain regions. Moreover, the patients' significant inability to execute dual tasks was not due to a larger area of overlap.

It is still controversial whether there is a central supervisor^{44–46} or not⁴⁷ while performing dual tasks. We found that the bilateral precuneus was additionally activated in dual tasks compared with single tasks in patients and aged normal controls.⁴⁸ However, in our study in young healthy subjects, we found no additional area was activated in performing the same dual tasks; all areas activated in the dual tasks were also activated by one or both of the component tasks.⁴⁹ These observations suggest that in PD patients and aged normal subjects, the precuneus may be activated as a central supervisor for dual task execution. Wenderoth and colleagues also found that the precuneus was additionally activated in executing bimanual motor tasks compared with performing unimanual movements.⁵⁰ Presumably, PD patients and aged normal controls need to recruit additional brain areas to compensate for their difficulty in executing dual tasks. By contrast, in young normal subjects an additional central supervisor is not necessary because these dual tasks are relatively easy for them. The precuneus was more activated in PD patients than in normal subjects, which suggests that patients may need more brain effort from a central executive to perform dual tasks. This phenomenon was detected not only while simultaneously performing a motor task and a cognitive task, but also during performance of two motor tasks simultaneously. Therefore, it is possible that the deficit of the central executive may exist in PD patients during performance of various dual tasks. An additional finding from that study is that there are more activations from the sum of two single tasks than that from the dual

task. These results indicate that neural activity of the dual task is less than a simple addition of the activations of the two component tasks. Some neural resources might be shared by the component tasks in order to execute the dual task efficiently.

Our studies demonstrated that practice can diminish dual task interference and improve performance in PD patients. Moreover, dual task interference in PD is due to multiple reasons: first, the limitation of attentional resources capacity is exceeded; second, PD patients perform the tasks less automatically compared with normal subjects; and third, the central executive may be defective in PD. These findings are really helpful to our understanding of dual task interference in PD. However, our knowledge of this phenomenon is still far from complete. For example, why PD patients have difficulty in switching attentional resource between tasks is unclear, and the central mechanism of this problem needs further investigation. ■



Tao Wu, MD, is an Associate Professor of Neurobiology in the Department of Neurobiology at the Beijing Institute of Geriatrics, Xuanwu Hospital. His main research interests are using functional neuroimaging methods, including functional MRI (fMRI) and positron emission tomography (PET), and other techniques of clinical neurophysiology to understand the physiology of normal human voluntary movement and the pathophysiology of different movement disorders, especially Parkinson's disease.



Mark Hallett, MD, is Chief of the Human Motor Control Section in the Intramural Program of the National Institute of Neurological Disorders and Stroke. For many years, his laboratory has been investigating mechanisms of normal human movement and the pathophysiology of movement disorders. Dr Hallett is an Associate Editor of *Brain* and the Editor in Chief of *World Neurology*, the newsletter of the World Federation of Neurology.

- Pashler H, Dual-task in simple tasks: data and theory, *Psychol Bull*, 1994;2:220-44.
- Friedman A, Polson MC, Dafoe DG, Gaskill S, Dividing attention within and between hemispheres: testing a multiple resources approach to limited-capacity information processing, *J Exp Psychol Hum Percept Perform*, 1982;8:625-50.
- Wickens CD, The structure of attentional resources. In: Nickerson R (ed.), *Attention and Performance VIII*, Hillsdale, NJ: Erlbaum, 1980;239-57.
- Navon D, Gopher D. On the economy of the human processing system. *Psychological Review* 1979;86: 214-255.
- Pashler H, Perception and production of brief durations: beat-based versus interval-based timing, *J Exp Psychol Hum Percept Perform*, 2001;27:485-93.
- Navon D, Miller J, Role of outcome conflict in dual task interference, *J Exp Psychol Hum Percept Perform*, 1987;13: 435-48.
- Frith CD, Bloxham CA, Carpenter KN, Impairments in the learning and performance of a new manual skill in patients with Parkinson's disease, *J Neurol Neurosurg Psychiatry*, 1986;49: 661-8.
- Schwab RS, Chafetz ME, Walker S, Control of two simultaneous motor tasks in normals and in Parkinsonism, *Arch Neurol Psychiatry*, 1954;72:591-8.
- Benecke R, Rothwell JC, Dick JP, et al., Performance of simultaneous movements in patients with Parkinson's disease, *Brain*, 1986;109:739-57.
- Benecke R, Rothwell JC, Dick JP, et al., Disturbance of sequential movements in patients with Parkinson's disease, *Brain*, 1987;110:361-79.
- Benecke R, Rothwell JC, Dick JP, et al., Simple and complex movements off and on treatment in patients with Parkinson's disease, *J Neurol Neurosurg Psychiatry*, 1987;50:296-303.
- Stelmach GE, Worringham CJ, The preparation and production of isometric force in Parkinson's disease, *Neuropsychology*, 1988;26:93-103.
- Castiello U, Bennett KM, The bilateral reach-to-grasp movement of Parkinson's disease subjects, *Brain*, 1997;120:593-604.
- Johnson MT, Kipnis AN, Lee MC, et al., Modulation of the stretch reflex during volitional sinusoidal tracking in Parkinson's disease, *Brain*, 1991;114:443-60.
- Brown RG, Marsden CD, Dual task performance and processing resources in normal subjects and patients with Parkinson's disease, *Brain*, 1991;114:215-31.
- Oliveira RM, Gurd JM, Nixon P, et al., Hypometria in Parkinson's disease: automatic vs. controlled processing, *Mov Disord*, 1998;13:422-7.
- Morris ME, Iansek R, Matyas TA, Summers JJ, Stride length regulation in Parkinson's disease: normalisation strategies and underlying mechanisms, *Brain*, 1996;119:551-68.
- Bond JM, Morris M, Goal-directed secondary motor tasks: their effects on gait in subjects with Parkinson disease, *Arch Phys Med Rehabil*, 2000;81:110-16.
- Morris M, Iansek R, Smithson F, Huxham F, Postural instability in Parkinson's disease: a comparison with and without a concurrent task, *Gait Posture*, 2000;12:205-16.
- Asburn A, Stach E, Pickering RM, Ward CD, A community-dwelling sample of people with Parkinson's disease: characteristics of fallers and non-fallers, *Age Ageing*, 2001;30:47-52.
- Ashburn A, Stack E, Fallers and non-fallers with Parkinson's disease (PD): the influence of a dual task on standing balance, *Mov Disord*, 2000;15(Suppl. 3):78.
- Marchese R, Bove M, Abbruzzese G, Effect of cognitive and motor tasks on postural stability in Parkinson's disease: a posturographic study, *Mov Disord*, 2003;18(6):652-8.
- Woodward T, Bunc D, Hunter M, Task switching deficits associated with Parkinson's disease reflect depleted attentional resources, *Neuropsychologia*, 2002;40:1948-55.
- Caligiuri MP, Heindel WC, Lohr JB, Sensorimotor disinhibition in Parkinson's disease: effects of levodopa, *Ann Neurol*, 1992;31:53-8.
- Dalrymple-Alford JC, Kalders AS, Jones RD, et al., A central executive deficit in patients with Parkinson's disease, *J Neurol Neurosurg Psychiatry*, 1994;57:360-67.
- O'Shea S, Morris ME, Iansek R, Dual task interference during gait in people with Parkinson disease: effects of motor versus cognitive secondary tasks, *Phys Ther*, 2002;82:888-97.
- Wu T, Hallett M, Neural correlates of dual task performance in patients with Parkinson's disease, *J Neurol Neurosurg Psychiatry*, 2008;79:760-66.
- Wu T, Hallett M, A functional neuroimaging study of automatic movements in patients with Parkinson's disease, *Brain*, 2005;128:2250-59.
- Levy J, Pashler H, Is dual task slowing instruction dependent?, *J Exp Psychol Hum Percept Perform*, 2001;27:862-9.
- Ruthruff E, Johnston JC, Van Selst MA, Why practice reduces dual task interference, *J Exp Psychol Hum Percept Perform*, 2001;27:3-21.
- D'Esposito M, Detre JA, Alsop DC, et al., The neural basis of the central executive of working memory, *Nature*, 1995;378:279-81.
- Sohn MH, Ursu S, Anderson JR, et al., Inaugural article: the role of prefrontal cortex and posterior parietal cortex in task switching, *Proc Natl Acad Sci U S A*, 2000;97:13448-53.
- Dreher JC, Grafman J, Dissociating the roles of the rostral anterior cingulate and the lateral prefrontal cortices in performing two tasks simultaneously or successively, *Cereb Cortex*, 2003;13:329-39.
- Collettea F, Olivier L, Van der Lindena M, et al., Involvement of both prefrontal and inferior parietal cortex in dual-task performance, *Brain Res Cogn Brain Res*, 2005;24:237-51.
- Szameitat AJ, Schubert T, Müller K, Von Cramon DY, Localization of executive functions in dual-task performance with fMRI, *J Cogn Neurosci*, 2002;14:1184-99.
- Erickson KI, Colcombe SJ, Wadhwa R, et al., Neural correlates of dual-task performance after minimizing task-preparation, *Neuroimage*, 2005;28:967-79.
- Jueptner M, Stephan KM, Frith CD, et al., Anatomy of motor learning. I. Frontal Cortex and attention to action, *J Neurophysiol*, 1997;77:1313-24.
- Owen AM, Evans AC, Petrides M, Evidence for a two-stage model of spatial working memory processing within the lateral frontal cortex: a positron emission tomography study, *Cereb Cortex*, 1996;6:31-8.
- Corbetta M, Shulman GL, Control of goal-directed and stimulus-driven attention in the brain, *Nat Rev Neurosci*, 2002;3:201-15.
- Woldorff MG, Hazlett CJ, Fichtenholtz HM, et al., Functional parcellation of attentional control regions of the brain, *J Cogn Neurosci*, 2004;16:149-65.
- Halsband U, Ito N, Tanji J, Freund HJ, The role of premotor cortex and the supplementary motor area in the temporal control of movement in man, *Brain*, 1993;116:243-66.
- Ivry RB, The representation of temporal information in perception and motor control, *Curr Opin Neurobiol*, 1996;6:851-7.
- Klingberg T, Roland PE, Interference between two concurrent tasks is associated with activation of overlapping fields in the cortex, *Brain Res Cogn Brain Res*, 1997;6:1-8.
- D'Esposito M, Detre JA, Alsop DC, et al., The neural basis of the central executive system of working memory, *Nature*, 1995;378:279-81.
- Dreher J, Grafman J, Dissociating the roles of the rostral anterior cingulate and the lateral prefrontal cortices in performing two tasks simultaneously or successively, *Cereb Cortex*, 2003;13:329-39.
- Schubert T, Szameitat AJ, Functional neuroanatomy of interference in overlapping dual tasks: an fMRI study, *Brain Res Cogn Brain Res*, 2003;17:733-46.
- Adcock RA, Constable RT, Gore JC, Goldman-Rakic SG, Functional neuroanatomy of executive processes involved in dual task performance, *Proc Natl Acad Sci U S A*, 2000;97:3567-72.
- Wu T, Hallett M, The influence of normal human ageing on automatic movements, *J Physiol*, 2005;562:605-15.
- Wu T, Kansaku K, Hallett M, How self-initiated memorized movements become automatic: a fMRI study, *J Neurophysiol*, 2004;91:1690-98.
- Wenderoth N, Debaere F, Snaert S, Swinnen SP, The role of anterior cingulate cortex and precuneus in the coordination of motor behaviour, *Eur J Neurosci*, 2005;22:235-46.