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Review article

Cognitive-motor dual-task interference: A systematic review of neural correlates

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ABSTRACT

Cognitive-motor interference refers to dual-tasking (DT) interference (DTi) occurring when the simultaneous performance of a cognitive and a motor task leads to a percentage change in one or both tasks. Several theories exist to explain DTi in humans: the capacity-sharing, the bottleneck and the cross-talk theories. Numerous studies investigating whether a specific brain locus is associated with cognitive-motor DTi have been conducted, but not systematically reviewed. We aimed to review the evidences on brain activity associated with the cognitive-motor DT, in order to better understand the neurological basis of the CMi. Results were reported according to the technique used to assess brain activity. Twenty-three articles met the inclusion criteria. Out of them, nine studies used functional magnetic resonance imaging to show an additive, under-additive, over- additive, or a mixed activation pattern of the brain. Seven studies used near-infrared spectroscopy, and seven neurophysiological instruments. Yet a specific DT locus in the brain cannot be concluded from the overall current literature. Future studies are warranted to overcome the shortcomings identified.

Contents

1. Introduction

The concurrent performance of a cognitive and motor task yields to a different pattern of interference. This includes four major isolated changes (motor task facilitation, motor task interference, cognitive task facilitation, and cognitive task interference), or the possible combinations of these observations, as well as no changes at all. Therefore totaling nine potential pattern of interferences (Plummer et al., 2013). Dual Task (DT) interference (DTi) occurs when the simultaneous performance of two different tasks results in the deterioration in one or both task performances.

Abbreviations: DT, dual task; ST, single task; MT, motor task; CT, cognitive task; fMRI, functional Magnetic Resonance Imaging; CCS, central capacity sharing; IFG, inferior frontal gyrus; L, left; BA, Broadman area; PrG, precentral gyrus; R, right; n.a., not applicable; EEG, electroencephalography; RT, reaction time; BN, bottleneck; MNI, Montreal Neurological Institute; ACC, anterior cingulate cortex; IPG, inferior parietal gyrus; PoG, postcentral gyrus; CG, cingulate gyrus; NIRS, near infrared spectroscopy; PFC, prefrontal cortex; SMA, supplementary motor area; CMC, corticomuscolar coherence; CV, coefficient of variation; SD, standard deviation; Hb, hemoglobin; MOBI, mobile brain/body imaging; ERP, event-related potential; DLPFC, dorso-lateral PFC; MEG, magnetoencephalography.

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As a specific kind of DTi, the cognitive-motor interference (CMi) occurs when the DT paradigm includes a motor task (i.g., walking) and a cognitive task (i.g., counting numbers backwards). During the DT performance, any modification from the reference single task (ST) condition in one or both subtasks is measured mostly as a percentage of change. This is also known as a DT cost (DTC) (Friedman et al., 1982). Whenever one or both of the performed ST(s) will change in a DT condition, a CMi will likely be present.

The underlying mechanisms of the DTi are still unclear. They have been described as a competition for attentional resources (Wickens, 1980) or a competition for information-processing neural pathways (Pashler, 1994). Three are the most influential "attentional" theories accepted to explain the CMI in humans: 1) the central capacity sharing model postulates that DTi is caused by a capacity limited process that can allocate capacity in a graded fashion or, in other words, when people perform two tasks simultaneously, resources must be re-distributed between the tasks (Friedman et al., 1982); 2) the bottleneck model, which is based on the idea that certain critical tasks must be carried out sequentially (and not in parallel), therefore a bottleneck arises when the information from two different tasks are processed by similar neural processor or networks (Pashler, 1994); and 3) the cross-talk model which suggests that if two tasks are from a similar domain and use the same neuronal populations, they will not disturb each other (Navon and Gopher, 1979; Navon and Miller, 1987); therefore such a kind of facilitation will come up when two tasks are from domains using similar pathways.

In the case of a DT involving walking as the motor task, every gait modification (such as slowing down) should be interpreted as an increase in cost for the involvement of cortical attentional processes while walking. More direct evidence of the correlation between cortical brain activation and a DT performance during walking have been shown in the last years, by the means of innovative instruments (e.g. near-infrared spectroscopy-NIRS, Mobile Electroencephalography). They are able to overcome the portability limitations of the conventional neuroimaging technologies. Besides walking, DT paradigms may involve many types of motor tasks, including upper limb movements to be simultaneously performed with a cognitive task.

DT performance also requires challenging attentional capacities (specifically the ability to divide the attention) and the integrity of the executive functions (Yogev-Seligmann et al., 2008). Executive functions refer to higher cognitive processes (e.g. volition, planning, purposive action, action monitoring, and cognitive inhibition) that use and modify information from many cortical sensory systems. This occurs in the anterior and posterior brain regions to modulate and produce effective, goal-directed actions and for the control of attentional resources (Lezak, 1995).

A great number of studies have been conducted in neuropsychology to understand the basis of DT and divided attention capacity in humans; but most of them applied a double cognitive task. More recently, fewer studies have been done to understand the neural correlates of CMi (using a DT paradigm involving a cognitive and a motor task), by the means of more advanced techniques (i.g. functional magnetic resonance imaging – fMRI, fNIRS). So far no paper has been published to provide an updated revision of the evidence available in literature on the neural correlates of cognitive-motor DT. With this paper we aimed to systematically review the studies conducted to reveal the neural correlates of cognitive-motor DT. We grouped findings according to the technique used to detect the brain related activity and by comparing the results with those available on cognitive–cognitive DT.

2. Methods

2.1. Inclusion criteria

We included all types of studies investigating the effect of performing a cognitive-motor DT on brain activity in healthy subjects. Brain activity had to be measured by neuroimaging techniques (fMRI, fNIRS, positron emission tomography – PET) or neurophysiological instruments (event-related potential – ERP, electroencephalography – EEG, magnetoencephalography – MEG). We excluded (a) studies which applied DT with similar task components, such as cognitive–cognitive and motor–motor DT, (b) studies including healthy subjects that only served as control of persons with any neurological disease, (c) studies investigating attention shifting, (d) studies investigating the effects of training, exercise intervention, therapy, drugs, or alcohol effects on DT and (e) non-English published studies.

2.2. Search strategy

The database PubMed was searched up to 1st of November 2015. Search strategies included the following keywords: (cognitive-motor interference OR "dual-task*" OR DT) AND (functional resonance magnetic imaging OR fMRI OR event-related potential OR ERP OR electroencephalography OR EEG OR magnetoencephalography OR MEG OR spectroscopy OR NIRS OR Positron Emission Tomography OR PET) AND (neural correlates OR brain activation OR brain activity); NOT (attention shifting OR practice OR training OR exercise OR intervention OR therapy OR drugs OR alcohol effects on DT). Inclusion and exclusion criteria were applied. Additionally; the reference lists of the included articles were checked for any additional relevant articles. The PRISMA flow diagram of the study selection process is illustrated in Fig. 1.

The following data were extracted and reported in Table 1: participant characteristics (number of subjects, age), single motor and cognitive tasks performed in the task paradigm, type of imaging technique used, clinical outcome, the neural correlates associated with the DT, and the anatomical brain locations (MNI co-ordinates, Talairach co-ordinates and Jülich co-ordinates) of the activated areas related to DT.

3. Results

The literature search identified a total of 23 articles, which met the inclusion criteria; all articles measured the behavioral and neural activity changes. (Gruber, 2001; Matthews et al., 2006; Just et al., 2008; Matthews et al., 2009; Serrien, 2009; Gazes et al., 2010; Remy et al., 2010; Holtzer et al., 2011; Van Impe et al., 2011; Johnson and Shinohara, 2012; Doi et al., 2013; Johannsen et al., 2013; Mandrick et al., 2013; Ohsugi et al., 2013; Wu et al., 2013; Beurskens et al., 2014; Blumen et al., 2014; De Sanctis et al., 2014; Meester et al., 2014; Mirelman et al., 2014; Nijboer et al., 2014; Kwon et al., 2015; Malcolm et al., 2015).

Out of the 23 included studies, 11 applied motor tasks involving the upper limb, 10 involved the lower limbs (mostly walking), and one involved a complex visual-motor task (driving scenario), and one involved an oculomotor task (see Table 1). Regarding the cognitive task applied, seven studies used an arithmetic task, five used a visual-based attention task, seven used a working memory task, two used a response-inhibition task, and two used language-related tasks (see Table 1).

3.1. Brain activity during cognitive-motor DT

In the following paragraphs we report on the main results of the cognitive-motor DT-related neural activity. We decided to report