Clinical Neurophysiology 127 (2016) 2509–2519

Contents lists available at ScienceDirect

Clinical Neurophysiology

journal homepage: www.elsevier.com/locate/clinph

Review

Movement-related potentials in Parkinson's disease

Dejan Georgiev [a,b], Florian Lange [c], Caroline Seer [c], Bruno Kopp [c], Marjan Jahanshahi [a,*]

[a] Sobell Department of Motor Neuroscience and Movement Disorders, Institute of Neurology, University College London, UK
[b] Department of Neurology, University Medical Centre Ljubljana, Ljubljana, Slovenia
[c] Department of Neurology, Hannover Medical School, Hannover, Germany

ARTICLE INFO

Article history:
Accepted 1 April 2016
Available online 12 April 2016

Keywords:
Movement-related potentials
Bereitschaftspotential
Contingent Negative Variation
Lateralized readiness potential
Parkinson's disease

HIGHLIGHTS

- We review the literature on movement-related potentials – the BP, the CNV and the LRP, in PD.
- There is clear evidence that the early BP and CNV are affected in dopamine-dependent manner in PD.
- LRP studies suggest impairment of motor control processes relating to the late preparation in PD.

ABSTRACT

To date, many different approaches have been used to study the impairment of motor function in Parkinson's disease (PD). Event-related potentials (ERPs) are averaged amplitude fluctuations of the ongoing EEG activity that are time locked to specific sensory, motor or cognitive events, and as such can be used to study different brain processes with an excellent temporal resolution. Movement-related potentials (MRPs) are ERPs associated with processes of voluntary movement preparation and execution in different paradigms. In this review we concentrate on MRPs in PD. We review studies recording the Bereitschaftspotential, the Contingent Negative Variation, and the lateralized readiness potential in PD to highlight the contributions they have made to further understanding motor deficits in PD. Possible directions for future research are also discussed.

Contents

Abbreviations: BP, Bereitschaftspotential; CNV, Contingent Negative Variation; CRT, choice reaction task; DBS, deep brain stimulation; DT, dopaminergic therapy; EEG, electroencephalography; ER, error rate; ERP, event-related potential; GPi, globus pallidus pars interna; LRP, lateralized readiness potential; M1, primary motor cortex; MEG, magnetoencephalography; MP, motor potential; MRP, movement-related potential; NFB, neurofeedback; NS, negative slope; PD, Parkinson's disease; PMP, premotor positivity; PSP, Progressive Supranuclear Palsy; RT, reaction time; SMA, supplementary motor area; SNPc, substantia nigra pars compacta; SRT, simple reaction time task; SPN, Stimulus Preceding Negativity; STN, subthalamic nucleus; TMS, transcranial magnetic stimulation; VP, vascular parkinsonism.

* Corresponding author at: Sobell Department of Motor Neuroscience and Movement Disorders, 33 Queen Square (Box 146), WC1N 3BG London, UK. Tel.: +44 20 3456 7890; fax: +44 (0)20 7278 5069.
E-mail address: m.jahanshahi@ucl.ac.uk (M. Jahanshahi).

http://dx.doi.org/10.1016/j.clinph.2016.04.004
1388-2457/

1. Introduction

Parkinson's disease (PD) is a chronic neurodegenerative disease marked by degeneration of the substantia nigra pars compacta (SNpc) and accumulation of aggregated α-synuclein in specific brain stem, spinal cord and cortical regions and characterized by disturbed motor functioning, clinically manifested as bradykinesia, rigidity and resting tremor (Lees et al., 2009). In addition to the lack of dopamine, which is the major pathophysiological hallmark of the disease, other neurotransmitter systems, such as those involving acetylcholine, noradrenaline and serotonin play a crucial role in the pathophysiology of the disease (Barone, 2010). Many different approaches to study the motor impairment in PD have been applied, one of which is the recording of event-related potentials (ERPs). ERPs are averaged amplitude fluctuations of the ongoing electroencephalographic (EEG) activity that are time locked to certain sensory, motor or cognitive events (Luck, 2014). The procedure is non-invasive and has been employed to study different cognitive and motor phenomena (Picton et al., 2000) with an excellent temporal resolution. The ERPs can be evoked by external stimuli, or can be 'emitted' by the brain as it processes information to produce a response. Movement-related potentials (MRPs) are ERPs associated with processes of voluntary movement preparation, initiation and execution in different paradigms, with the movement execution encompassing the time immediately after movement completion (Colebatch, 2007). In general, two main types of anticipatory slow waves preceding movements can be distinguished: the Bereitschaftspotential (BP), and the Contingent Negative Variation (CNV). In addition, movement preparation can also be studied by analyzing the lateralized readiness potential (LRP), which is derived by subtracting the ipsilateral from the contralateral movement-related slow wave activity over the motor cortex. The Stimulus Preceding Negativity (SPN), which is sometimes regarded too as an MRP (Brunia et al., 2012), was primarily conceptualized by the observation, that a slow negativity similar to the CNV can be seen even without a motor response (Brunia et al., 2012). SPN will not be discussed here, as this potential is strictly speaking not an MRP; while in MRPs amplitude rises until the time-point of responding, the negative slope in SPN ends before stimulus onset – long before the response onset.

The aim of this review is (1) to give an overview of MRPs in PD by highlighting the major findings from the studies published to date and (2) to highlight possible directions for future research. In each section (e.g. BP, CNV, LRP), the ERP will be first defined, followed by a review of the literature on the corresponding potential in PD. Studies measuring the classical amplitude/latency based approach were included in this review. The cognitive ERPs in PD are reviewed in a separate paper (Seer et al., under review).

2. The Bereitschaftspotential in Parkinson's disease

When a simple voluntary movement (e.g. finger movement) is made, a slowly rising, negative potential appearing 2–1 s prior to the movement can be registered in the EEG at central electrodes (Jahanshahi and Hallett, 2002; Shibasaki and Hallett, 2006). This potential – the Bereitschaftspotential – was first described about 50 years ago (Deecke et al., 1969; Gilden et al., 1966; Kornhuber and Deecke, 1964, 1965), and it has been broadly accepted in the research and clinical community as a useful tool for exploring motor physiology in neurological populations (Table 1).

A few distinct components can be discerned during the course of the BP (Fig. 1). The first part of BP, starting 2–1 s before a movement, is the so-called 'early BP', and has a more diffuse, yet midline distribution over the cortex. The early BP is thought to reflect more general preparation for the forthcoming movement (Jahanshahi and Hallett, 2002; Shibasaki and Hallett, 2006) and its generation has been linked to the pre-supplementary motor area (pre-SMA), supplementary motor area (SMA) and the lateral premotor cortex bilaterally corresponding to the Brodmann area 6 (Brunia et al., 2012; Shibasaki and Hallett, 2006). The early BP is followed by the 'late BP' (Shibasaki and Hallett, 2006), starting 400–500 ms before the movement, characterized by a sudden shift of the gradient of the negativity at the central electrodes contralateral to side of movement (e.g. C1 and C3 for the right sided movements and C2 and C4 for the left-sided movements according to 10–20 system). This late BP has been related to activation of the primary motor cortex (Brunia et al., 2012). As we will see later on, there is indeed evidence that these two BP components are functionally related to different brain areas. It is worth noting that in the literature different terminology has been used to refer to these earlier and later phases of the BP (Jahanshahi and Hallett, 2002). Therefore, while 'early BP' has been variably referred to as simply 'BP', 'BP1' (Deecke et al., 1969), or negative slope 1 (NS1), 'late BP' has been referred to as BP2 (Deecke et al., 1969), negative slope (NS') (Shibasaki and Hallett, 2006), negative slope 2 (NS2). The components following late BP – the premotor positivity (PMP) seen 50 ms before the movement, and the motor potential (MP) occurring 10 ms before the movement onset, as well as the post-motor potentials (Shibasaki and Hallett, 2006) – will not be discussed in this review because they have been less investigated in PD.

The major clinical presentation of PD is impairment of movement related to the dysfunction of the basal-ganglia-thalamo-cortical circuits (including the SMA, which is strongly implicated in the generation of the BP) (Jahanshahi and Hallett, 2002). Therefore, it seems reasonable to expect BP alterations in patients with PD. The studies, which have recorded the BP in PD, are summarized in Table 1. Indeed, most of the studies (Dick et al., 1987, 1989; Jahanshahi et al., 1995) reviewed in detail elsewhere (Praamstra et al., 2002) have found BP amplitude reduction in patients with PD (but see Barrett et al. 1986). In contrast, prolongation of the latency of the BP, regarded as a marker of the slowness of movements in PD, was only infrequently reported (Shibasaki et al., 1978). As prolonged BP latency in PD was not replicated in later studies, this finding could be a result of the suboptimal averaging methodology used in this early study on BP (Praamstra et al., 2002).

MRP studies have looked in more detail at different aspects of the BP in PD. For example, Dick et al. (1989) found lower amplitude of the early BP and higher amplitude of the late BP in PD patients off dopaminergic medication, interpreted as indicating reduced SMA activity and compensatory activity of M1. In an earlier study from the same group (Dick et al., 1987) by comparing PD patients on and off dopaminergic medication and healthy participants after taking L-dopa or a dopaminergic antagonist, the authors found that L-dopa administration increased the amplitude of the early BP in both PD patients and healthy controls. In healthy controls, dopaminergic antagonist decreased the amplitude of the early, but not the late BP. In addition, there was no effect of L-dopa on the late BP in healthy controls and there was no difference in the peak BP (late BP) between PD off medication and healthy subjects. In contrast, chronic administration of L-dopa in de novo PD patients increased the amplitude of the late, but not the early BP (Feve et al., 1992) (Fig. 2).

Even though the results of the studies presented above differ considerably, the difference in the results could be due to methodological differences, such as acute (Dick et al., 1987) vs. chronic L-dopa administration (Feve et al., 1992). Notwithstanding these inconsistencies, both studies suggested that the early BP amplitude reduction in PD is sensitive to dopaminergic medication. Later studies shed light on the different generators of the early vs. late BP components. In a combined PET-EEG study, Jahanshahi et al. (1995) (Fig. 3) compared self-initiated and externally triggered