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Movement-related beta oscillations show high intra-individual reliability

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ABSTRACT

Oscillatory activity in the beta frequency range (15–30 Hz) recorded from human sensorimotor cortex is of increasing interest as a putative biomarker of motor system function and dysfunction. Despite its increasing use in basic and clinical research, surprisingly little is known about the test-retest reliability of spectral power and peak frequency measures of beta oscillatory signals from sensorimotor cortex. Establishing that these beta measures are stable over time in healthy populations is a necessary precursor to their use in the clinic.

Here, we used scalp electroencephalography (EEG) to evaluate intra-individual reliability of beta-band oscillations over six sessions, focusing on changes in beta activity during movement (Movement-Related Beta Desynchronization, MRBD) and after movement termination (Post-Movement Beta Rebound, PMBR). Subjects performed visually-cued unimanual wrist flexion and extension. We assessed Intraclass Correlation Coefficients (ICC) and between-session correlations for spectral power and peak frequency measures of movement-related and resting beta activity. Movement-related and resting beta power from both sensorimotor cortices was highly reliable across sessions. Resting beta power yielded highest reliability (average ICC=0.903), followed by MRBD (average ICC=0.886) and PMBR (average ICC=0.663). Notably, peak frequency measures yielded lower ICC values compared to the assessment of spectral power, particularly for movement-related beta activity (ICC=0.386–0.402). Our data highlight that power measures of movement-related beta oscillations are highly reliable, while corresponding peak frequency measures show greater intra-individual variability across sessions. Importantly, our finding that beta power estimates show high intra-individual reliability over time serves to validate the notion that these measures reflect meaningful individual differences that can be utilised in basic research and clinical studies.

1. Introduction

Oscillatory activity is ubiquitous in the brain and considered essential for the encoding and processing of information (Buzsáki and Draguhn, 2004). Neuronal oscillations in the beta frequency band (15–30 Hz), prevalent in sensorimotor cortex, are related to motor activity, as supported by a range of electroencephalography (EEG) and magnetoencephalography (MEG) studies showing a modulation of beta oscillations with active and passive movement (Alegre et al., 2002), motor imagery (McFarland et al., 2000; Nakagawa et al., 2011) and movement observation (Babiloni et al., 2002). Beta power decreases just prior to and during movement (Movement-Related Beta Desynchronization, MRBD), followed by a transient post-movement increase above pre-movement levels (Post-Movement Beta Rebound, PMBR) (Pfurtscheller and Lopes Da Silva, 1999; Pfurtscheller et al., 1998a; Salmelin and Hari, 1994; Stancak and Pfurtscheller, 1995), with each of these dynamics differentially modulated by experimental factors (for review see Kilavik et al., 2013; Van Wijk et al., 2012). MRBD is typically observed in both contralateral and ipsilateral sensorimotor cortices during unimanual movements, while PMBR typically shows a contralateral preponderance (Salmelin and Hari, 1994; Stancak and Pfurtscheller, 1995). In addition to changes in power within the beta frequency band, individual peak frequency has been shown to be a behaviourally meaningful parameter of oscillatory activity (Kilavik et al., 2012) that differs across regions within the sensorimotor cortex (Salmelin and Hari, 1994), and which is of increasing interest considering recent attention on extrinsic neurostimulation approaches for modulating motor outputs (Guerra et al.,

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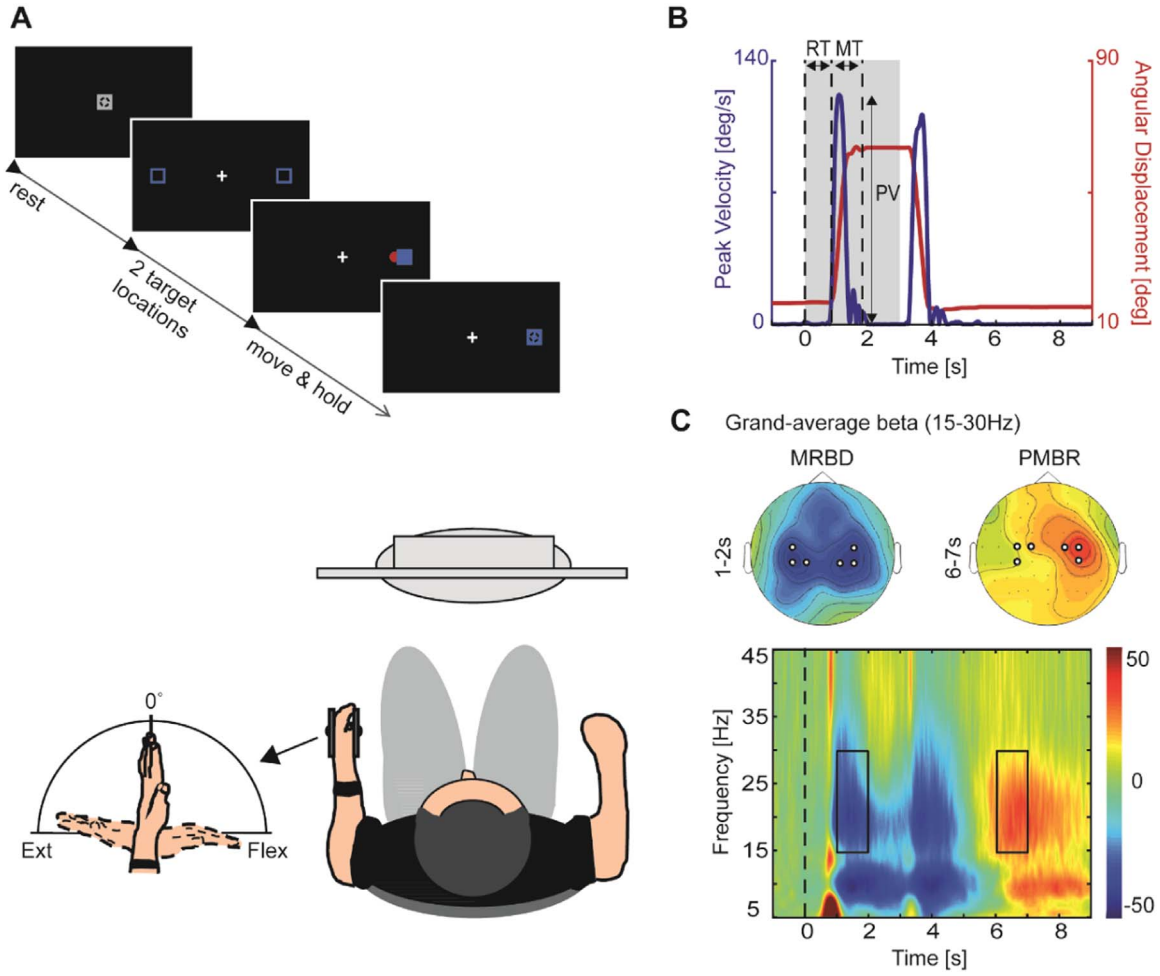

Fig. 1. Experimental setup and measurements. A, Experimental paradigm. Subjects sat in front of a computer monitor and were instructed to perform wrist movements to move the wrist cursor (red circle) from the initial start position (grey square) to one of two target positions (blue squares) upon target presentation. B, Calculation of reaction time (RT), movement time (MT) and peak velocity (PV) where the grey patch represents target presentation. Velocity profile (blue line) and wrist angular displacement (red line) are shown for one trial of an example participant. C, Topographical distribution (top panel) and time-frequency map (bottom panel) of movement-related beta activity. Topographical plots of grand-average beta power revealed electrodes of peak change (highlighted as black-and-white disks) overlying contra- and ipsilateral sensorimotor cortices. Time-frequency map for pooled electrodes contralateral to moving hand showing two distinct time windows of peak changes in beta activity (MRBD: 1–2 s; PMBR: 6–7 s). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article).

2016; Joundi et al., 2012; Pogosyan et al., 2009). However, despite extensive research, the functional relevance of beta oscillatory activity is still debated (Engel and Fries, 2010; Jenkinson and Brown, 2011; Pfurtscheller et al., 1996).

Direct manipulation of beta oscillations through the application of transcranial alternating current stimulation (tACS) at beta frequency can produce a slowing of movements (Joundi et al., 2012; Pogosyan et al., 2009) suggesting a causal role of sensorimotor beta oscillatory activity in motor control. Alterations in beta activity are also observed in disease states such as stroke (Rossiter et al., 2014a) and Parkinson's disease (Brown, 2007; Heida et al., 2014; Heinrichs-Graham et al., 2013; Little and Brown, 2014). Both patient populations show a reduction in the amplitude of MRBD together with deficits in some aspects of motor control, suggesting that MRBD may be a general assay of the state of the motor system, irrespective of the underlying pathophysiology. In addition, changes in beta oscillations have been observed with ageing, with resting beta power increasing as a function of age (Rossiter et al., 2014b; Heinrichs-Graham and Wilson, 2016), and the amplitude of MRBD and PMBR increasing during development (Gaetz et al., 2010).

Given its potential role as neurophysiological marker of motor system function and dysfunction, rhythmic activity at beta frequencies has received considerable interest in both basic and clinical research (Nicolo et al., 2015; Takemi et al., 2015; Ward, 2015; Wu et al., 2015). Measurements of beta activity may provide insight into the dynamics of disease, potentially providing a clinically relevant biomarker. However, despite prevalent use of EEG/MEG to explore beta oscillatory dynamics in normal brain functioning and pathology, to the best of our knowledge, no studies have systematically assessed their test-retest reliability across multiple recordings. If measures of beta oscillations in healthy individuals are highly variable between separate sessions (high intra-individual variability), EEG assays of beta oscillatory activity are unlikely to be useful as biomarkers (Mayeux, 2004). Reliable spectral estimates of oscillatory activity are therefore a prerequisite for studies designed to test longitudinal changes in clinical and non-clinical populations or therapeutic interventions.

In the current study, we comprehensively assessed the test-retest reliability of spectral power and peak frequency measures of movement-related beta activity in a group of healthy subjects across several weeks. Since MRBD and PMBR estimates quantify movement-related changes in beta power *relative* to a pre-movement (resting) baseline, and recent work by Heinrichs-Graham and colleagues (Heinrichs-Graham and Wilson, 2016) suggests a direct relationship between MRBD and pre-movement baseline beta activity, we also evaluated the reliability of beta oscillations during the pre-movement (resting) baseline period of our motor task. For measures of beta oscillations to be