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# Cortical beta oscillations and motor thresholds differ across the spectrum of post-stroke motor impairment, a preliminary MEG and TMS study

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ABSTRACT

*Background:* Cortical oscillatory activity in the beta frequency band (13–30 Hz) is associated with voluntary movement and may be altered in motor disorders such as stroke.
*Methods:* We used a multimodal case-series approach to investigate movement-related beta oscillations, cortical excitability and upper-limb motor-function in 10 chronic stroke-patients across a broad range of motor-impairment. Assessments included: (i) whole-head magnetoencephalography (MEG) during a voluntary motor task; (ii) resting and active motor-thresholds to transcranial magnetic stimulation (TMS); and (iii) assessments of upper-limb motor-function.
*Results:* MEG revealed distinct patterns of movement-related beta oscillations according to motor-function. An elongated event-related desynchronisation (ERD) was correlated with poorer motor-function ($p=0.004$) whereas an elongated event-related resynchronisation (ERS) was correlated with higher motor function and lower TMS motor thresholds on the more-affected side ($p=0.014$ and $p<0.001$, respectively). Oscillation amplitude and laterality were also correlated with motor-function, where a stronger ERD/ERS and a greater relative contribution from the ipsilesional hemisphere were correlated with better motor-function ($p=0.016$, $p=0.025$). Unlike TMS responses and motor-function, the temporal profile of beta oscillations was largely symmetrical for movements of the more- and less-affected hands.
*Conclusions:* Beta ERD/ERS patterns differ across the post-stroke motor impairment spectrum, and are bilaterally similar after stroke. Both the amplitude and duration of beta oscillations relate to post-stroke motor-function.
*Significance:* The contralesional hemisphere is not unaffected post-stroke. Caution is needed when generalising imaging and neurophysiological findings from patients with moderate to high motor ability to the more heterogeneous general stroke population and particularly those with low levels of residual voluntary motor-function.



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## 1. Introduction

The neurophysiological mechanisms of cortical movement control and motor recovery after stroke are not well understood despite motor impairment being the most common outcome after stroke that affects up to 85% of survivors (Kelly-Hayes et al., 2003; Paul et al., 2007). It is generally assumed that the mechanisms of stroke-induced impairment are constant regardless of the extent of motor dysfunction. Transcranial magnetic stimulation (TMS) (Bütefisch et al., 2003; Liepert et al., 2000b) and functional magnetic resonance imaging (fMRI) (Johansen-Berg et al., 2002; Ward et al., 2003) are commonly used to probe the cortical changes associated with motor impairment after stroke, particularly in patients with high or moderately-high levels of residual voluntary motor-function. However, TMS is constrained by its reliance on evoked responses rather than measurements of spontaneous or task-related brain activity, and fMRI by its limited temporal resolution and assumptions of indirect neurovascular coupling (Logothetis and Wandell, 2004). Magnetoencephalography (MEG) avoids such limitations by measuring the magnetic fields generated by synchronously active pyramidal neurons in the cortex (Murakami and Okada, 2006). Thus MEG is independent of neurovascular coupling and the relatively sluggish haemodynamic response of the brain. This confers a superior millisecond temporal resolution that can provide detailed information about dynamic neuronal activity associated with the planning, preparation and execution of a voluntary movement (Cheyne, 2013).

The characteristic oscillation frequencies associated with neural activity in the awake human brain can be studied with MEG. Oscillations in the beta frequency band (13–30 Hz) are strongly associated with voluntary movement (Cheyne, 2013; Pfurtscheller, 1981; Salmelin and Hari, 1994). They are present in the healthy motor cortex at rest, and are characteristically reduced or 'desynchronised' during the planning and execution of a motor task, known as an event-related desynchronisation (ERD) (Pfurtscheller and Lopes da Silva, 1999). A rebound event-related synchronisation (ERS) or increase in beta power above baseline is typically observed following movement (Pfurtscheller et al., 1996). Pharmacological (Hall et al., 2011; Muthukumaraswamy et al., 2013) and TMS (Aono et al., 2013; Chen et al., 1998; Takemi et al., 2013) studies suggest that the strength and peak frequency of beta oscillations are related to cortical excitability.

In the healthy brain, a robust spatiotemporal pattern of beta ERD/ERS has been characterised for simple voluntary movements (Pfurtscheller and Lopes da Silva, 1999), passive movements (Keinrath et al., 2006) and motor imagery (Burianova et al., 2013; Pfurtscheller et al., 2005). Changes to beta-band activity can occur with healthy ageing (Rossiter et al., 2014c) and sensorimotor disorders including stroke (Rossiter et al., 2014b), Parkinson's disease (Heinrichs-Graham et al., 2014; Jenkinson and Brown, 2011) and amyotrophic lateral sclerosis (Bizovicar et al., 2014; Kasahara et al., 2012), suggesting an association between altered beta oscillations and sensorimotor pathology.

The nascent use of MEG post-stroke has focused on changes to resting-state (Tecchio et al., 2005, 2006; Westlake et al., 2012) and passively evoked somatosensory oscillations (Laaksonen et al., 2012; Tecchio et al., 2007). Due to the methodological difficulties inherent in eliciting voluntary movements in the affected limbs of stroke patients, little is known about the effects of stroke on movement-related beta oscillations. Recent seminal evidence suggests that movement-related beta ERD amplitudes are attenuated after stroke, indicating that these oscillations may be a useful index of motor cortical impairment and recovery

**Table 1 – Patient demographics and motor-function.**

| | Age | Sex | Time post-stroke (months) | Stroke type | Dom/non-dom hemiparesis | WMFT-tt (s)[a] | FMA[b] | MAL QOM[c] | BBT[d] MA / LA | Grip (kg) MA / LA | Finger-tapping (Hz) MA/ LA | PCA | Upper-limb motor function | Resting/ active MEP present | ERD/ ERS present |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 64 | m | 21 | isch | dom | 89.37 | 21 | 11 | 0/48 | 14/47 | 0.9/4.9 | −1.49 | | −/− | +/− |
| 2 | 45 | f | 25 | haem | non-dom | 81.37 | 28 | 10 | 0/50 | 3/41 | 0.8/4.9 | −1.48 | Low | −/− | +/− |
| 3 | 37 | f | 45 | isch | dom | 53.47 | 48 | 39 | 0/35 | 6/22 | 0.7/4.5 | −0.97 | | −/+ | +/− |
| 4 | 75 | m | 39 | isch | dom | 28.41 | 63 | 59 | 28/47 | 28/38 | 1.3/3.9 | −0.12 | | −/− | +/− |
| 5 | 50 | m | 8 | isch | non-dom | 5.25 | 61 | 73 | 27/53 | 32/68 | 1.2/4.7 | 0.06 | Mod | +/+ | +/+ |
| 6 | 50 | m | 20 | haem | non-dom | 4.91 | 62 | 143 | 27/51 | 23/40 | 2.1/4.9 | 0.28 | | +/+ | +/+ |
| 7 | 59 | f | 4 | isch | dom | 3.23 | 66 | 138 | 49/47 | 28/26 | 4.8/4.6 | 0.79 | | +/+ | +/+ |
| 8 | 65 | m | 3 | isch | non-dom | 1.96 | 65 | 102 | 44/50 | 43/42 | 5.2/5.4 | 0.82 | | NA | +/+ |
| 9 | 62 | f | 3 | isch | dom | 2.81 | 66 | 145 | 50/46 | 28/25 | 5.4/4.9 | 0.87 | High | +/+ | +/+ |
| 10 | 48 | m | 6 | haem | dom | 2.06 | 65 | 132 | 62/64 | 58/62 | 5.5/5.3 | 1.24 | | +/+ | +/+ |

haem: haemorrhagic, isch: ischaemic; dom: dominant side, non-dom: non-dominant side; MA: more-affected side, LA: less-affected side;
[a] WMFT-tt mean time for 15 timed tasks, maximum possible time 120 s;
[b] FMA upper-limb motor subscale, maximum score 66;
[c] MALQOM score quantifying use of the more-affected hand and arm in everyday activities, maximum score 150;
[d] BBT: Box and Block Test, number of 2.5 $cm^3$ wooden blocks moved in 60 s; finger-tapping frequency in Hz over a 15 s timed trial; PCA: overall score of motor-function generated by principal component analysis; upper-limb motor function: classified using the scheme of Thompson-Butel and colleagues (Thompson-Butel et al., 2014). For MEPs & ERD/ERS, + indicates present for the more-affected side, − indicates absent, NA: data not available.