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Chapter 5

THE BEREITSCHAFTSPOTENTIAL IN JERKY MOVEMENT DISORDERS

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J.H.T.M. Koelman
A.F. van Rootselaar

ABSTRACT

OBJECTIVE
To assess the diagnostic value of the Bereitschafspotential (BP) in jerky movement disorders.

METHODS
A cross-sectional case series of 48 patients with psychogenic jerks, Gilles de la Tourette (GTS) or myoclonus was investigated. We measured the BP prior to the spontaneous jerk and voluntary wrist extension. In addition, the various jerky movements were imitated by 25 healthy subjects.

RESULTS
For patients with psychogenic jerks, we observed significantly more BPs, however the BP was not identified prior to self-paced wrist extensions in 59% of cases. In contrast, none of the patients with the clinical diagnosis of myoclonus had a BP prior to their jerks but did have a BP prior to intentional wrist extension. In GTS we demonstrated a BP in a minority of cases preceding motor tics, with a shorter duration in comparison to patients with psychogenic jerks. In healthy control subjects, a BP was found preceding all movements in all cases. The absence of a BP prior to intended wrist extension had a sensitivity of 0.59, specificity of 0.98 and positive likelihood ratio of 25 for the diagnosis of psychogenic jerks.

CONCLUSIONS
We demonstrate that the BP can aid in the differentiation of jerky movements. Patients with psychogenic jerks significantly more often have a BP prior to their jerks and with a significantly earlier onset compared to GTS patients. A novel finding of our study is the absence of a BP prior to intentional movements for patients with psychogenic jerks. Validation in a prospective cohort is needed.
INTRODUCTION
The classification of jerky movements is a clinical challenge on the border of neurology and psychiatry. Underlying causes encompass a spectrum of neuropsychiatric disorders ranging from myoclonus to motor tics and psychogenic jerks. (1) Diagnosis is usually based on clinical phenomenology. Myoclonic jerks are brief, irregular muscular contractions whereas psychogenic jerks and motor tics are repetitive stereotyped movements that vary in frequency, distribution and severity. (2,3,4) The diagnosis of psychogenic jerks is based on positive clinical clues, such as acute onset of the disorder, spontaneous (albeit temporarily) remissions, distractibility, variability (over time) and inconsistency. (3) The diagnosis of Gilles de la Tourette’s syndrome is based on clinical criteria as specified in the DSM-IV, with an onset of tics prior to the age of 18 and at least multiple motor and one or more vocal tics. (5) Although these diagnostic categories might suggest a clear distinction between a neurological and a psychiatric aetiology, the clinical features in an individual patient are not always specific for one disorder. Key to the diagnosis of tics is the presence of a premonitory urge preceding the movements and the ability of suppression. However, not all patients with tics experience these sensations and we have reported patients with psychogenic jerks with these sensations prior to their jerks. (1,4) Another commonly encountered feature is psychiatric co-morbidity, such as anxiety disorders, obsessive-compulsive disorder and major depressive disorder. However, psychiatric co morbidity is also reported in myoclonus. (6) Due to these overlapping clinical features, misdiagnosis of jerks has been reported and may potentially lead to inadequate treatment. (3,7)
Electrophysiological investigations may be able to support the clinical diagnosis of psychogenic movement disorders and provide a higher degree of diagnostic certainty. (8,9) The Bereitschaftspotential (BP) is an early cortical activation preceding self-initiated movements. (10) In clinical practice, presence and duration of a BP preceding a jerk of unknown aetiology can potentially be used to differentiate between myoclonus, psychogenic jerks and tics. However, a systematic group comparison on the ability of the BP to differentiate between myoclonus, tics and psychogenic jerks is lacking. The current study aims to investigate the value of the BP in the differentiation of myoclonus, motor tics and psychogenic jerks. Importantly, the BP has never been reported to precede myoclonus. However, a pre-movement cortical spike is a typical finding in cortical myoclonus. (2) For patients with psychogenic jerks, Terada and colleagues have demonstrated a BP in five out of six patients. (11) The potential started between 2,1 to 0,7 seconds at the central cortical regions before the onset of the psychogenic jerks. Obeso and colleagues demonstrated that simple motor tics were not preceded by a pre-movement potential, whereas mimicked voluntary jerks were. (12) In contrast, Karp and co-workers did find a BP in a few Tourette patients, but this BP had a later onset (‘late BP’). (13) Therefore, we hypothesized that a BP prior to tics, if present, starts later compared to a BP preceding a self-paced movement. Moreover, we hypothesize that patients with clinically definite psychogenic jerks have early onset BPs, and the BP is not identified in myoclonus. Thus, the presence and onset of the BP may aid in differentiation of the various jerky movements.
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METHODS

INCLUSION OF PARTICIPANTS

We included: 1) all consecutive patients with jerks seen between 2007 and 2010 by the hyperkinetic movement disorder specialists in our hospital, diagnosed with either myoclonus, psychogenic jerks, or motor tics; 2) from our movement disorders registry, patients seen between 2000 and 2007 with myoclonus, psychogenic jerks, or motor tics; and 3) patients referred from the Tourette Syndrome Patients’ Association with primarily motor tics. Patients had to meet clinical criteria for myoclonus, tic or ‘clinically established’ psychogenic jerks and should have isolated jerking of the arm or leg. (2,5,14) In total, 51 patients were included in the study. In addition, 25 healthy control subjects, matched as a group on age, gender and handedness to all patients, were included. Exclusion criteria for healthy subjects were a history of neuro- or psychiatric disorders or use psycho-active drugs. Handedness of all participants was determined with the standard Edinburgh Handedness Inventory. (15) The study was approved by the medical ethics committee and all participants gave written informed consent.

ANALYSIS OF PARTICIPANTS

One patient with psychogenic jerks and two patients with Gilles de la Tourette were excluded from further analysis because there were too few artefact free epochs. The data of 48 patients (32 men) in total, with a median age of 43 years (range=21-74) was analysed. Demographic characteristics are shown in Table 1. One patient was left handed and two were ambidextrous. We also included one left handed control and one ambidextrous healthy subject. Five patients with isolated myoclonic jerks of the hands and arms accompanied by slight dystonia in other body parts were included. Patients were DYT11 negative, and myoclonus was classified as subcortical based on an EMG burst duration of over 100 ms and absence of a pre-movement cortical spike and were described previously. (16) Patients with Tourette had several tics, but all had at least one frequently occurring simple motor tic. Five patients had additional complex tics. Although 12/16 patients with Tourette’s syndrome had simple ocular tics, we averaged bodily simple motor tics that occurred separately from ocular tics. Three patients with Tourette had co-morbid obsessive-compulsive disorder (OCD) and one had co-morbid ADHD. Psychogenic jerks were unilateral in 10 out 29 patients and mainly distributed in the trunk (n=18) and leg (n=15). The psychogenic patients were significantly older than GTS and myoclonus patients (median age 52, 34 and 38 respectively; p<0.001). The myoclonus group contained a female majority (p<0.001). No overall statistical differences with respect to age, gender, and handedness were observed between patient and control subjects. All patients with myoclonus and tics had a childhood onset of the jerks. Two patients with myoclonus abstained from clonazepam for over 24 hours prior to the EEG-EMG recordings. Except for the one patient with Tourette and ADHD who used methylphenidate, all patients were free of medication during recordings. Clinical characteristics are summarised in Table 1.
DATA ACQUISITION
Participants were placed reclining on a bed with their eyes open. First, patients were instructed to let their jerks occur spontaneously without suppression. Thereafter, patients were instructed to make a fast extension movement with their dominant wrist repeatedly every 5 seconds by mentally counting backwards from 5 to 0. A minimal number of 75 jerks was recorded per condition. Healthy controls first performed the wrist extension task with two separate sessions for each side. Control subjects performed separate series of jerks of the right biceps, right thigh and abdomen, resembling the patients’ jerks. These isolated jerky movements were self-pace with a minimum interval of 5 seconds. Recordings took 60 to 75 minutes in patients, depending upon frequency of the jerks, and 50 minutes in control subjects.

Data were recorded with Ag/AgCl surface electrodes (Brainlab; OSG bvba, Rumst, Belgium) with a sample frequency of 1000 Hz and was analog band pass filtered at 0.005 – 250 Hz. EEG was recorded based on the conventional 10-10 system. Nineteen electrodes were placed on the scalp, covering the frontal, precentral, central and parietal regions bilaterally, and included C1, C2, Cz, C3, C4, Pz, Fz, FC3, FC4, CP3, CP4, O1 and O2. EEG electrodes were referenced to linked ears and electrode impedance was kept below 5 kOhm and the EMG below 20 kOhm. Bipolar EMG electrodes were placed on five muscles with the most frequent jerks, specific in every patient. Electro-oculogram (EOG) was recorded in the horizontal and vertical axes.

**Table 1** Overview of clinical characteristics

<table>
<thead>
<tr>
<th></th>
<th>#</th>
<th>Age</th>
<th>M : F</th>
<th>Disease duration</th>
<th>Uni lateral</th>
<th>Hands</th>
<th>Arm</th>
<th>Face</th>
<th>Trunk</th>
<th>Leg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Psychogenic</td>
<td>29</td>
<td>52 (25-74) *</td>
<td>19:10</td>
<td>5 (0.5-40)</td>
<td>10</td>
<td>0</td>
<td>10</td>
<td>3</td>
<td>18</td>
<td>15</td>
</tr>
<tr>
<td>Tourette</td>
<td>14</td>
<td>34 (21-65)</td>
<td>12:2</td>
<td>22 (5-58)</td>
<td>1</td>
<td>4</td>
<td>11</td>
<td>12</td>
<td>3</td>
<td>7</td>
</tr>
<tr>
<td>Myoclonus</td>
<td>5</td>
<td>38 (24-59)</td>
<td>1:4*</td>
<td>18 (1-53)</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Control subjects</td>
<td>25</td>
<td>46 (21-76)</td>
<td>16:9</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 1: Median is reported (range) for age, disease duration (years). Sum scores are reported for the other characteristics. #=number of participants. Gender: M=male, F=female * indicates significant differences.
IDENTIFICATION OF EMG BURST ONSET AND AVERAGING

Offline data analysis was performed with commercial software (BrainVision Analyzer version 1.03). The EEG signal was not filtered. The EMG signal was high pass filtered at 30 Hz, low pass at 250 Hz (with 50 Hz notch filter) and rectified. Markers were set at burst onset (t0) of the first muscle involved in the spontaneous jerks. In case of inconsistent spontaneous jerking, the earliest involved muscle was marked. For both the spontaneous jerks and for the intentional movements, all traces were divided in 4 s. segments (2 s. before - 2 s. after t0). All segments were visually inspected and trials with artefacts (e.g. eye blinks, movement artefact) were removed. Baseline correction was applied during the interval from -2000 to -1900 ms prior to burst onset and averaged.

CRITERIA FOR THE BEREITSCHAFTSPOTENTIAL

In this study, for clarity and reproducibility, we defined criteria for the presence of the BP prior to starting the recordings. Up to now, no established criteria for the BP exist. Several studies report a multitude of phases (up to eight) that can be distinguished in healthy control subjects; however clinical studies do not report any specific criteria. (10) In this study, we classify two components, the early and late BP as those are clearly distinguishable. (see Figure 1) In clinical practice the signal-to-noise ratio is often not as good as in control subjects. The BP has been known to have a great inter- and intrasubject variability. (17, 18) The BP was defined present in case the following criteria are met. Firstly, the slowly rising (negative) deflection started at least 1000 (early BP) or between 1000 and 500 ms (late BP) before the movement onset in the EMG (t0). Secondly, at t0 the amplitude was at least 5 μV, based on healthy control studies. (18) We chose not to measure the maximum peak negativity as this is often influenced by movement artefact. Third, movement artefact should not interfere with the BP, defined as absence of a slow rising potential over the occipital electrodes (O1, O2). If the same deflection was present at O1 or O2, the deflection at Cz was considered to be due to artefact and not labelled as a BP. All patients with ‘borderline’ BP’s not meeting the BP criteria, but with a pre-movement negativity were rated by two board-certified clinical neurophysiologists blinded for subject status. Thereafter, patients were discussed and consensus was reached on either presence or absence of the BP. Averages with an amplitude below -2,5 μV at t0 were considered to be absent. Our criteria for the BP are summarised in Figure 1.
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STATISTICS

Group statistics were conducted using the Statistical Package for the Social Sciences (SPSS) software 16.0 and reported with a significance threshold of p< 0.05. Between group comparisons were conducted with nonparametric statistics (Mann Whitney U and Kruskal-Wallis analysis of variance) and Pearson’s correlation coefficient was used to test correlations. The sensitivity, specificity, positive and negative likelihood ratio were calculated using direct computation from 2 × 2 tables.

RESULTS

SPONTANEOUS JERKS

In 25 patients with psychogenic jerks, a BP was present, of which 22 were early BPs (Table 2). None of the myoclonus patients had a BP prior to their spontaneous jerks. Six out of fourteen GTS patients had a BP prior to tics, two of which were late BPs. Patients with psychogenic jerks had significantly more (early) BPs preceding their spontaneous jerks as compared to GTS (general BP and early BP both p=0.003; late BP p=0.709) and myoclonus (p<0.001). The onset of the BP was earlier for patients with psychogenic jerks compared to BPs onset for patients with TS (p=0.020). Representative recordings of individual cases per participant group are displayed in figure 2.

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**Figure 1** Illustration of EEG trace depicting the criteria for the Bereitschaftspotential (BP) as defined in this study. We defined a negative potential starting 2 to 1 seconds prior to the onset of the burst in the EMG (termed t=0) as an early BP and between 1 and half of a second as a late BP. The amplitude of the BP had to be at least 5 μV. EMG = electromyography.
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Figure 2 Representative recordings of individual cases per participant group are displayed. Grand averages of EEG (Cz) and EMG (earliest involved muscle in the jerky movement) are displayed of spontaneous jerks in patients and wrist extension in a control subject. Note the early Bereitschaftspotential (BP) onset in the psychogenic patient and healthy control subject and the late onset in the Tourette case. In the patient with myoclonus we demonstrate an absent BP. EMG = electromyography.

Table 2 Overview of BP findings

<table>
<thead>
<tr>
<th>Total included</th>
<th>Spontaneous jerky movements</th>
<th>Intended wrist extension</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BP (%)</td>
<td>Onset BP</td>
</tr>
<tr>
<td>Psychogenic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>25 (86) *</td>
<td>1195 *(700-2410)</td>
</tr>
<tr>
<td>Tourette</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>6 (43)</td>
<td>915 * (510-1700)</td>
</tr>
<tr>
<td>Myoclonus</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0 (0)</td>
<td>-</td>
</tr>
<tr>
<td>Controls</td>
<td></td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 2: The total number of participants and BPs is reported per condition (spontaneous jerks or intended wrist extension task) with the percentage in between brackets. Median is reported (range) for onset of BP (msec). * indicates significant differences.
**INTENDED SELF-PACED WRIST EXTENSION**

Seventeen of the 29 patients with psychogenic jerks had an absent BP prior to wrist extension, whilst 15 of these patients did show a BP prior to their spontaneous jerks. Two patients with psychogenic jerks had no BP prior to voluntary wrist extension, nor prior to spontaneous jerks. Ten patients showed a BP preceding both self-paced wrist extension and their spontaneous jerk and two others had a BP prior to wrist extension, but no BP prior to spontaneous jerks. In the 14 GTS patients, a BP was present before self-paced wrist extension with their dominant arm (Table 2). In one patient GTS interpretation of the averaged EEG segments was difficult to interpret because of EOG and EMG artefacts and labelled as an ‘uncertain’ BP by both clinical neurophysiologists. A significant difference in the presence of a BP prior to wrist extension between patients with psychogenic jerks and TS was found (p=0.003). All patients with myoclonus had a BP prior to wrist extension. TS patients had more frequent BPs compared to patients with psychogenic jerks on self-initiated wrist extension (p=0.003), but no significant differences were found when compared to myoclonus (spontaneous BP: p=0.085, wrist BP: p=0.55).

We explored the following confounding factors between all patients groups. Age did not statistically significantly correlate with the presence of the BP, nor did gender or use of medication (r= 0.167; 0.216; 0.99). Patient groups significantly differed on disease duration (p=0.0001; with myoclonus and GTS having the longest disease duration) and unilateral distribution of jerks (p=0.022) as myoclonus was distributed symmetrically.

**CONTROL SUBJECTS**

All control subjects had BPs prior to both wrist extension and self-paced imitation of the jerks of patients. Control subjects reported that the extension of the right wrist was the easiest task to perform and imitation of the jerks of the right thigh was most difficult. Significant differences were found between the BP preceding the wrist-extension task and self-paced imitation, the latter had an earlier onset and higher amplitude at t=0 (right wrist < right thigh : p=0.005 onset, p<0.001 amplitude; right wrist < abdomen p=0.046 onset, p=0.024 amplitude). Execution of the wrist extension task with the left or right wrist did not differ significantly (p=0.165 onset, p=0.808 amplitude). An overview of the results in control subjects is depicted in Table 3.
**Table 3** Overview of findings in control subjects

<table>
<thead>
<tr>
<th>Movement type</th>
<th>BP present</th>
<th>Onset</th>
<th>Amplitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wrist extension</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right wrist</td>
<td>100%</td>
<td>1275 (960-1800)</td>
<td>6.96</td>
</tr>
<tr>
<td>Left wrist</td>
<td>100%</td>
<td>1305 (1030-1630)</td>
<td>7.7</td>
</tr>
<tr>
<td>Self-paced imitation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right biceps</td>
<td>100%</td>
<td>1335 (1050-1680)</td>
<td>10.5</td>
</tr>
<tr>
<td>Right thigh</td>
<td>100%</td>
<td>1360 (1060-1580)</td>
<td>12.75</td>
</tr>
<tr>
<td>Abdominal</td>
<td>100%</td>
<td>1430 (970-1680)</td>
<td>8.7</td>
</tr>
</tbody>
</table>

Table 3: Control subject performed wrist extensions of either the right or left wrist with a set interval of 5 seconds by mentally counting backwards from 5 to 0. At the self-paced (without external triggering) imitation conditions participants contracted the right biceps, thigh or their abdomen in separate sessions upon their own intention (no triggering, no set interval, no cue). Onset times are displayed in msec and amplitude in \( \mu V \). Medians are displayed (range). Total number of control subjects is 25.

**Table 4** Diagnostic value of the Bereitschaftspotential in jerky patients

<table>
<thead>
<tr>
<th>Psychogenic jerks</th>
<th>Sensitivity</th>
<th>Specificity</th>
<th>Positive LLR</th>
<th>Negative LLR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Present BP</td>
<td>0.86</td>
<td>0.68</td>
<td>2.7 (1.4-5.4)</td>
<td>0.2 (0.08-0.53)</td>
</tr>
<tr>
<td>Present early BP</td>
<td>0.76</td>
<td>0.79</td>
<td>3.6 (1.5-8.82)</td>
<td>0.3 (0.16-0.6)</td>
</tr>
<tr>
<td>Present late BP</td>
<td>0.1</td>
<td>0.9</td>
<td>0.98 (0.18-5.3)</td>
<td>1 (0.87-1.15)</td>
</tr>
<tr>
<td>Absent BP prior to wrist extension *</td>
<td>0.59</td>
<td>0.98</td>
<td>25 (3.5-179)</td>
<td>0.42 (0.27-0.65)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tics</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Present BP</td>
<td>0.43</td>
<td>0.26</td>
<td>0.58 (0.31-1.1)</td>
<td>2.16 (1.17-4)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Myoclonus</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Present BP</td>
<td>0</td>
<td>0.28</td>
<td>0 (0)</td>
<td>3.6 (3.2-4)</td>
</tr>
</tbody>
</table>

Table 4: The diagnostic value of the presence of the BP is displayed per patient group. Note that the absence of the BP prior the wrist extension task is displayed as well. BP = Bereitschaftspotential; LLR = Likelihood ratio with (95% confidence interval). * This analysis includes control subjects as well, as they also performed the wrist extension task (resulting in total n=73).
**Diagnostic value of the BP**

The presence of the BP (both early and late) prior to psychogenic jerks had a sensitivity and specificity of 0.86. It had a positive likelihood ratio (LLR) of 2.7 (95% confidence interval (CI); 1.4-5.4) and a negative LLR of 0.2 (CI: 0.08-0.53) (see Table 4). Prior to motor tics in Tourette, the presence of the BP had a sensitivity of 0.43 and specificity of 0.42 (positive LLR: 0.58 (CI: 0.31-1.1) and negative LLR 2.16 (CI: 1.17-4). The presence of a BP in myoclonus had a sensitivity and positive LLR of 0 and specificity of 0.28 with a negative LLR of 3.6 (CI: 3.2-4). For the analysis of the absence of a BP prior to intended wrist extension we included the control subjects (total n=73), which had a sensitivity of 0.59 and specificity of 0.98 for psychogenic jerks. The positive LLR of an absent BP prior to intended wrist extension was 25 (CI; 3.5-179) and the negative LLR 0.42 (CI: 0.27-0.65).

**Post-hoc analysis of predefined BP criteria**

Prior to the start of the measurements of this study, we defined BP criteria. All ‘borderline BPs’ were rated by two board-certified clinical neurophysiologists, but this only resulted in one pre-movement negativity to be termed present. Regarding the amplitude criterion at t₀, a post-hoc analysis demonstrated that a less stringent cut-off of -2.5 μV amplitude of the pre-movement negativity would have resulted in more present BPs prior to spontaneous jerks in the psychogenic (n=27; 93%) and Tourette cases (n=7; 50%) (see Figure 3 A). Application of the -2.5 μV amplitude in the wrist extension task would have resulted in all Tourette to have had a BP, just like all myoclonic patients and controls (see Figure 3 B). The patients with psychogenic jerks would have had a BP in 18 (62%) cases. In other words, this would have resulted in 11 patients with psychogenic jerks having an absent BP prior to wrist extension. Therefore, the absent BP prior to the wrist extension task would remain highly specific for the diagnosis of psychogenic jerks.
Figure 3 Scatter-plots depicting the individual amplitudes of all participants with mean (annotated by) per participant group. The dotted line indicates the amplitude threshold of -5 μV at t₀ (= time of onset of EMG) for the presence of the Bereitschaftspotential (BP) as applied in this study. All ‘borderline’ BPs between -2.5 and -5 μV (annotated with the gray area) were rated by two board certified neurologists and it was decided based on all BP criteria (amplitude, shape, artefact and signal to noise ratio) whether this pre-movement negativity is a BP. (A) Depicts the results of the spontaneous jerks and (B) of the wrist extension task, the latter includes the results of the healthy control subjects.
DISCUSSION

This study is the first to assess the BP in a large case series of ‘clinically established’ psychogenic jerks, GTS and myoclonus. The majority (86%) of patients with psychogenic jerks had an early BP preceding their jerks (median onset 1195 ms). Interestingly, in more than half of patients with psychogenic jerks the BP was not identified prior to the self-paced task of voluntary wrist extension. Moreover, the absence of a BP prior to intended wrist extension had high specificity for the diagnosis psychogenic jerks. In GTS, we demonstrated a BP preceding motor tics in almost half (43%) of cases. The BP in GTS had with a shorter duration (median onset 915 ms, ‘late BP’) in comparison to patients with psychogenic jerks. In contrast, for none of the patients with the clinical diagnosis of myoclonus a BP was identified. In addition, the jerky movements were imitated by 25 healthy control subjects, for whom we found a BP preceding all movements in all cases.

In our patients with psychogenic jerks, we observed significantly more BPs with an early onset (longer duration) compared to GTS and myoclonus patients. In this study, the BP prior to a spontaneous jerk was considered absent in four psychogenic patients. In our opinion, the absence of the BP does not exclude a psychogenic aetiology per se.(1,19) In this study, we reproduce earlier findings that motor tics in Gilles de la Tourette syndrome can indeed be preceded by a BP in a minority of cases.(13) However, we found that tics are not just preceded by late BPs, but demonstrate BPs with early onset as well. Our findings might implicate reconsideration of the commonly held view of all motor tics as pure involuntary (non-intended) movements, as this might imply that some tics are produced intentionally. Alternatively, it could also reflect the awareness of the imminent tic (a.k.a. urge). The pathophysiological overlap of the urge and a BP prior to motor tics is an interesting direction for future studies.

A novel observation of this study is the absence of the BP in most patients with psychogenic jerks prior to an intended action (wrist extension task). The absence of a BP prior to an intentional task has a high specificity for psychogenic jerks. In contrast, all patients with Tourette and myoclonus and control subject do demonstrate a BP prior to intended wrist extensions. It has been shown that the level of intension and motivation influence the presence of the BP.(11) Other influencing factors on the amplitude and time course of the BP are level of attention, preparatory state, movement selection (free selected versus fixed pattern) and complexity of the movement.(11) We replicated these findings with our observation that self-paced imitation of jerks by healthy controls was preceded by a significantly earlier and higher amplitude BP (Table 3). The absent BP in psychogenic patients prior to intentional wrist extension might therefore represent part of the pathophysiological mechanisms that underlies psychogenic jerks. It has been observed previously that the execution of ‘voluntary’ tasks is impaired in psychogenic tremor.(20) It is postulated that patients with a psychogenic movement disorder are unable to access circuitry normally used for intended movements. Although still hypothetical, it has been suggested that attentional
bias towards the psychogenic movement disorder influences the performance of intentional tasks. Regarding intention, a recent study with the classical Libet paradigm demonstrated that patients with psychogenic tremor judged their feeling of intention to move significantly later compared to control participants.\textsuperscript{(21)} It was postulated that the sense of volition prior to movement is impaired in patients with psychogenic tremor, which is in line with the absence of a BP in psychogenic jerks as found in our study.

Our findings in healthy controls imply that our recording protocol and predefined BP criteria were adequate to detect BPs in all healthy controls and that they were motivated to perform all movements. Especially leg movements were subjectively scored to be most difficult by the participants, which was accompanied by the most prominent BP. The influence of complexity of the movement on the magnitude and onset of the BP may explain the relatively long BP we found in one patient with Tourette. It started 1700 ms prior to the complex tic. This patient was also diagnosed with OCD. This complex tic consisted of tonic wrist extension and flexion, starting on the right and then following on the left. His OCD entailed focus on symmetry, especially symmetric execution of motor tics. This might explain the prolonged voluntary motor preparation as resembled in the early BP. Future studies in OCD might investigate the presence of the BP prior to compulsive behaviour.

Unfortunately, consensus criteria for the BP are currently lacking. Prior to the start of the measurements of the current study, we defined criteria for the presence of the BP to avoid a bias towards the presence of a BP in low signal to noise recordings containing movement artefacts. We are aware that the predefined criteria as applied in this study for the presence of the BP, influence the results of our study. The post-hoc analysis of the amplitude criterion for the presence of the BP demonstrates that, even after accepting lower amplitudes pre-movement negativities as a present BP, 11 psychogenic cases have an absent BP prior to the intended wrist extension. Consensus needs to be reached on the electrophysiological criteria of the BP, as the annotation of a BP prior to a spontaneous jerk in an individual case in clinical practice has important implications for treatment. The presented study provides guidance for these electrophysiological criteria. Future studies are needed to assess the diagnostic value of the BP in a prospective cohort of patients.

Another limitation of this study include the inability to make definite clinical diagnoses of psychogenic jerks, as this could only be ‘proven’ in due time, if the movement disorders resolves spontaneously or with suggestion.\textsuperscript{(3, 14)} Second, our patient groups differed in age and gender, but this difference did not confound the presence of a BP. Moreover, our study included a relatively small sample of patients with myoclonus. The movement artefact may be bothersome in individual patients and limits the use of EEG-EMG jerk-locked backaveraging as a clinical test. We had to exclude 3 patients based on movement artefacts and contamination of the EEG with EMG and EOG.

In conclusion, although the Bereitschaftpotential is by no means ideal as a ‘gold standard’ test for either psychogenic jerks or motor tics, it does provide support to the clinical differentiation of jerks. For patients with psychogenic jerks, the presence of the BP prior to the onset of jerks and in particular absence of a BP prior to an intended movement (task) provides diagnostic certainty which is an important clinical asset in the continuum of jerky movements.
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REFERENCES


