Wearable monitoring of positive and negative myoclonus in progressive myoclonic epilepsy type 1

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Highlights

- Wearable surface electromyography and three-dimensional accelerometry can detect both positive and negative myoclonus in EPM1 patients.
- Monitored signal parameters correlate with the myoclonus severity of arms with action of Unified Myoclonus Rating Scale.
- Monitoring-based myoclonus index follows fluctuations in the degree of myoclonus at the patient’s home.

Abstract

Objective: To develop and test wearable monitoring of surface electromyography and motion for detection and quantification of positive and negative myoclonus in patients with progressive myoclonic epilepsy type 1 (EPM1).

Methods: Surface electromyography and three-dimensional acceleration were measured from 23 EPM1 patients from the biceps brachii (BB) of the dominant and the extensor digitorum communis (EDC) of the non-dominant arm for 48 hours. The patients self-reported the degree of myoclonus in a diary once an hour. Severity of myoclonus with action was evaluated by using video-recorded Unified Myoclonus Rating Scale (UMRS). Correlations of monitored parameters were quantified with the UMRS scores and the self-reported degrees of myoclonus.

Results: The monitoring-based myoclonus index correlated significantly \((p < 0.001)\) with the UMRS scores \((p = 0.883 \text{ for BB and } p = 0.823 \text{ for EDC})\) and with the self-reported myoclonus degrees \((p = 0.483 \text{ for BB and } p = 0.443 \text{ for EDC})\). Ten patients were assessed as probably having negative myoclonus in UMRS, while our algorithm detected that in twelve patients.

Conclusions: Wearable monitoring was able to detect both positive and negative myoclonus in EPM1 patients.

Significance: Our method is suitable for quantifying objective, real-life treatment effects at home and progression of myoclonus.

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1. Introduction

Progressive myoclonic epilepsy type 1 (EPM1, Unverricht-Lundborg disease) is a neurodegenerative disorder that usually starts at a young age (6–16 years) and is characterized by stimulus-sensitive and action-activated myoclonus, and tonic-clonic epileptic seizures (Kälviäinen et al., 2008). The diagnosis of...
EPM1 is established in a patient with suggestive symptoms and either biallelic abnormal CCC-GGC-CCC-GCG dodecamer repeat expansions in the CSTB gene or compound heterozygosity for a CSTB dodecamer repeat expansion and a CSTB sequence variant identified by molecular genetic testing. The severity of symptoms varies between subjects. Some can live an almost normal life, that is create a family and be independent in activities of daily living, but others are severely disabled and have an institutionalized life (Crespel et al., 2016; Hypponen et al., 2015). There is no etiologic treatment for EPM1, but the symptoms can be relieved to some extent with antiseizure drugs with antymyoclonic properties (Genton, 2010). The myoclonus can be, however, very drug resistant (Crespel et al., 2016).

In EPM1, myoclonus is already present at early stages. It may appear as positive or negative. Positive myoclonus means an involuntary and quick jerk of muscles that may occur spontaneously. It may be induced by stimuli, an action, or even an intention to move (Avanzini et al., 2016; Crespel et al., 2016). Action myoclonus can make daily activities such as eating difficult or even impossible. Negative myoclonus, instead, means a sudden and brief loss of muscular tone that may lead, for example, to the loss of posture or the dropping of objects from hands (Rubboli and Tassinari, 2006).

Clinically, the severity of myoclonus can be evaluated by an experienced rater using video-recorded Unified Myoclonus Rating Scale (UMRS). In UMRS, myoclonus severity is scored in context with stimulus, during rest and action, and during functional tests (e.g., writing or pouring water), separately for different parts of the body: arms, legs, trunk, and neck (Frucht et al., 2002). UMRS evaluation has, however, limitations. Firstly, it is based on subjective observations and its assessment requires a professional rater. Secondly, it measures myoclonus at only one time point, though in EPM1 patients, myoclonus severity fluctuates within the same day or between days. At early stages of EPM1, myoclonus typically occurs at awakening. Later, it becomes movement-related and increases with psychic and physical stress. During rest and sleep, myoclonus is often less severe or even absent (Crespel et al., 2016). The assessment is usually done during the short clinic visit, instead of continuously in the home environment, which would be important because of the fluctuation of myoclonus severity. Despite having been used in clinical drug trials, due to the aforementioned reasons and high variability, UMRS has been found as an inadequate marker of symptom assessment (Kalviainen et al., 2016). Negative myoclonus may be difficult to detect if it does not lead to a visible loss of posture.

Symptom diaries can be also used to evaluate the degree of myoclonus. They can provide a long-term estimation of the amount of myoclonus in the typical surroundings and during daily activities. However, this is also subjective rating and varies highly between subjects. Other challenges of paper-based or even digital diary filling are low adherence causing missing data and time-related errors. However, this is also subjective rating and varies highly between subjects. Other challenges of paper-based or even digital diary filling are low adherence causing missing data and time-related errors. Despite having been used in clinical drug trials, due to the aforementioned reasons and high variability, UMRS has been found as an inadequate marker of symptom assessment (Kalviainen et al., 2016). Negative myoclonus may be difficult to detect if it does not lead to a visible loss of posture.

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Surface electromyography (EMG) and accelerometry can provide valuable information about the nature and the source of symptoms (e.g., tremor and myoclonus) in movement disorders (Chen and Chen, 2020). Surface EMG shows the pattern of a single myoclonus discharge, the rhythmicity of consecutive myoclonus discharges, and the spread of myoclonus among different muscles (Shibasaki, 2006). Accelerometry measures the amplitude and frequency of myoclonus (Nijssen et al., 2010). At rest, positive myoclonus occurs in EMG as a burst of brief (duration of around 100 ms) myoclonic potentials that may occur synchronously in agonist and antagonist muscles. During muscle contraction, it occurs as a brief (duration 50–100 ms) suppression of muscle activity (Avanzini et al., 2016). Electrocencephalography (EEG) may help in evaluating the origin of myoclonus (Chen and Chen, 2020). Simultaneous EEG–EMG measurement may reveal the cortical origin of myoclonus by jerk-locked back by averaging from the onset of myoclonus in EMG to pre-myoclonic cortical potential in EEG (Cassim and Houdayer, 2006). Myoclonus severity has been found to inversely correlate with the peak frequency of cortico-muscular coherence (CMC) in the beta band when using magnetoencephalography (MEG) combined with EMG (Franceschetti et al., 2016). Negative myoclonus shows in EMG as a silent period for 50–120 ms (Chen and Chen, 2020). It requires a tonic contraction to become apparent, and it may be preceded by a time-locked EEG spike (Rubboli and Tassinari, 2006).

Wearable sensors have developed significantly during the most recent decade, enabling continuous measurement of physiological signals, movement, and physical activity during daily activities. These simple techniques have been suggested for monitoring movement disorders, and they can provide continuous, objective information about motor dysfunction with minimal hospitalization and low cost (Jalloul, 2018). Long-term measurements enable detecting fluctuations in motor symptoms objectively at different times of the day and between days. To our knowledge, ambulatory measurements of surface EMG and motion have not yet been used to study myoclonus and its fluctuations over several hours at patient homes. It is possible that this type of measurement tool could help in the objective evaluation of myoclonus severity, disease progression, and real-life treatment effects.

We aimed to develop and test a method for home monitoring of myoclonus using wearable sensors of surface EMG and three-dimensional (3D) accelerometry (ACC). The hypotheses were as follows: 1) both positive and negative myoclonus can be objectively detected in the measured surface EMG and ACC data, 2) the calculated surface EMG and ACC parameters correlate with UMRS-based myoclonus severity of arms, and 3) ambulatory surface EMG and ACC measurements follow fluctuations in the degree of myoclonus at the patient’s home.

2. Methods

2.1. Subjects and clinical characteristics

This study was approved (statement 410/2019) by the ethics committee of the North Savo Hospital District. A written informed consent was obtained from all subjects participating in the study. The subject group consisted of 23 patients with genetically confirmed EPM1. Patients were invited from a previous EPM1 study cohort (Hypponen et al., 2015). Patients with mild, moderate, and severe myoclonus were selected based on previous evaluations. Additionally, four recently diagnosed patients were invited to participate in the study. The patients’ clinical characteristics and the antiseizure medications at the study visit are given in Table 1. Fourteen patients were females and nine were males, and the mean age of the patients was 29 ± 10 years (mean ± standard deviation (SD)). The patients had been diagnosed as having EPM1 17 ± 9 years prior.

The EPM1 patients were evaluated with video recorded UMRS through standardized means (Frucht et al., 2002). Videos were rated for positive and negative myoclonus by an experienced scorer (J.H.). The frequency and amplitude of the myoclonus during finger-to-nose action were scored using the standard protocol (Frucht et al., 2002). These scores are given for the dominant and the non-dominant arm in Table 1. In the UMRS video recordings, visible episodes of muscle tone loss during arm tasks or standing and walking were indicative of negative myoclonus. Negative myoclonus was scored as 0 when no episodes of muscle tone loss were observed, and the probability of negative myoclonus was thus considered to be less than 50%. If the probability of negative myoclo-
Myoclonus was assessed to be more than 50% (score 1), its severity was scored on scale (0–3). The results of the negative myoclonus evaluations are given in Table 1.

### 2.2. Home monitoring and symptom diaries

The myoclonus measurement using wearable EMG and accelerometer was started in Kuopio University Hospital before the beginning of UMRs recording, and it was continued at home for up to the following 48 hours. Patients and their caregivers were instructed to fill in a symptom diary once an hour at home simultaneously with the measurement. In the symptom diary, the patients were asked to score their degree of myoclonus (MD) between 0 and 6 (scores: 0 = no myoclonus, 1 = occasional myoclonus, 2 = mild myoclonus, 3 = moderate myoclonus, 4 = moderate myoclonus that deteriorates from time to time, 5 = severe myoclonus almost continuously, and 6 = unable to move because of disabling myoclonus). In addition, they were instructed to report possible prolonged myoclonic seizures and tonic-clonic seizures, sleeping periods, and other symptoms with specifications. Additional medications taken for myoclonus were also reported in the symptom diary (Table 1).

Surface EMGs and three-dimensional acceleration signals were registered continuously by using two small-sized (48 mm × 29 mm × 12 mm, weight 13 g) FarosEMG measurement units (Bittium Biosignals Ltd.) fixed near the measuring electrodes.
EMG signals were sampled at the frequency of 1000 Hz and acceleration signals at 50 Hz, respectively. Signals were analog–digital (AD) –converted (14-bit) and stored in the FarosEMG measurement unit. During measurement, the only limitation to patients’ daily activities was to avoid the wetting of the measurement units. After 48 hours of recording, the measurement unit was sent back to the clinic, and the data were transferred from the unit to a personal computer (PC) for analysis.

2.3. Data analysis

Signal analysis was performed with Matlab 2019b (Mathworks®) and statistical analysis with IBM SPSS Statistics 27 (IBM Corp.). EMG signals were first high-pass filtered (9th order Butterworth filter with 10 Hz cut-off) to remove possible low-frequency artefacts caused by movement. The acceleration components (ACCx, ACCy and ACCz, in all three directions, respectively) were used to calculate the acceleration signal resultant (ACC). ACC signals were band-pass filtered for 2–10 Hz, a range that contains myoclonic movements with characteristic frequency (Nijsen et al., 2010). The band-pass filtering of ACC between 2–10 Hz was performed to remove the voluntary movements (<2 Hz) and the high frequency artefacts (>10 Hz) from the signal before analysis.

2.3.1. Analysis of positive myoclonus

Signal parameters were calculated for each 1-s long EMG and ACC signal epoch and finally averaged over for each 5-minute-long signal segment. Five parameters were calculated from EMG signals and one from ACC signals:

- **sample kurtosis (k)** to measure the EMG signal impulsiveness (myoclonic jerks)
- **correlation dimension (D2)** to measure the EMG signal complexity
- **recurrence rate (RECC)** to measure the percentage of recurring patterns (repeating myoclonic jerks)
- **root-mean square amplitude (RMS)** to reveal periods of increased muscle activity
- **burst frequency (BF)** to measure possible synchronization of muscular jerks
- **maximum value of ACC power spectrum** (MACC) to measure the concentration of movement power at a specific myoclonus frequency

Parameters k, D2 and RECC were calculated as described previously (Rissanen et al., 2012). BF was calculated from the EMG envelope as the number of times per second that the EMG envelope exceeded a previously chosen threshold level, and its duration was in the range of 50–143 ms. BF can reveal possible synchronization of motor unit action potentials since the EMG signal is a sum of several motor unit action potentials of one muscle. The synchronization was not quantified here between the muscles. The ACC power spectrum was estimated using Welch’s averaged periodogram method (epoch length 2 s, overlap 75%).

The first principal component (MEMC) of the original EMG parameters (k, D2, RECC, RMS, and BF) was calculated as a weighted sum of the original parameters as described previously (Rissanen et al., 2012). Finally, the overall myoclonus index (MI) was calculated as

\[
MI = MEMC \cdot MACC
\]

and was used for further analysis of home-based monitoring data. MI combined the acceleration measurement with the EMG measurement. It gets the highest value, when both the MEMC and MACC are increased (i.e., when both signals show myoclonic features).

Correlation was quantified pairwise between the measurement parameters and the UMRS-based myoclonus scores (-amplitude × frequency) of arms with action by using the Spearman’s rank correlation coefficient. Multiple correlations were controlled by False Discovery Rate (FDR) analysis using Benjamini-Hochberg method. The maximum values of k, RECC, RMS, BF, MACC and MI, and the minimum value of D2 during the finger-to-nose testing of UMRS were used for correlation analysis. These values were used for correlation analysis since the UMRS score is based on the worst myoclonus seen during the finger-to-nose testing. In addition, correlation was quantified between the MI and the myoclonus degree (MD) self-reported by the patients in the symptom diaries. The mean values of MI for each reported hour were used for correlation analysis. The similarities and differences between symptom diaries and monitoring data were also evaluated by visual inspection. We used Wilcoxon signed rank test for repeated variables to test, if there are significant differences between the consecutive measurement days in the sum of MI divided by the measurement length.

2.3.2. Analysis of negative myoclonus

The detection of negative myoclonus segments was based on EMG data, and they were detected during the UMRS evaluation of arms with action (arms forward with palms down for 10 s, followed by extension of wrists for 10 s) with the following criteria:

1. a loss of muscular tone for 50 ms
   a. maximum difference between EMG values < a
   b. sum of differences between consecutive absolute EMG values < b
2. a preceding muscle activation (60–180 ms before muscular loss)
   a. sum of absolute EMG values < c
3. a following muscle activation (60–180 ms after muscular loss)
   a. sum of absolute EMG values < c

where a, b, and c are experimentally defined threshold values.

3. Results

3.1. Detection of positive and negative myoclonus from measured signals

Positive myoclonus was observed in the measured EMG signal as spikes corresponding to muscular jerks, and in the ACC signal as fluctuation corresponding to myoclonic movements. The measured EMG and ACC signals during UMRS-based finger-to-nose testing for two patients (Patient 14 and Patient 7) with different levels of myoclonus severity are presented in Fig. 2. The patient (Patient 14) with a higher UMRS score, has many more myoclonic spikes in the EMG and myoclonic movements in the ACC than Patient 7 with a lower score.

Short episodes of loss of muscle tone were found in the EMG data (EDC and/or BB) of 12 patients during the UMRS evaluation of arms with action by using the developed algorithm (described in Section 2.3.2). In ten of these patients, this finding of negative myoclonus was concordant with the UMRS assessment (the probability above 90% in video recorded UMRS as described in Section 2.1). The remaining two patients (Patients 4 and 21) had been considered, based on UMRS, as probably not having negative myoclonus. Fig. 3 shows the EMG and ACC signals of one patient (Patient 5) with negative myoclonus in addition to positive myoclonus during the extension of wrists. The short losses of muscle
3.2. Correlation with the UMRS scores

Correlation analysis showed moderate to strong correlations between the UMRS-based myoclonus frequency × amplitude scores and the EMG and acceleration parameters (Table 2 and Fig. 4). More severe myoclonus, according to UMRS, is related to an increased number of recurring spikes and lower complexity of EMG as well as with the increased power of involuntary movements in ACC measurements. The monitoring-based MI correlates strongly and significantly with the UMRS-based frequency × amplitude in both arms ($\rho = 0.883$ for dominant BB and $\rho = 0.823$ for non-dominant EDC, $p < 0.001$).

3.3. EMG and acceleration parameters during home monitoring of myoclonus

EMG- and ACC-based parameters followed the subjective diary-based changes in MD during the 48-hour long monitoring.

Fig. 2. Surface electromyography (EMG) and acceleration (ACC) signals of two patients (14 and 7) with positive myoclonus during finger-to-nose-testing in video-recorded Unified Myoclonus Rating Scale (UMRS). The UMRS-based frequency $\times$ amplitudes were $3 \times 4$ for Patient 14 and $1 \times 1$ for Patient 7. The red arrows point to positive myoclonus spikes.

Fig. 3. A representative 14-s long electromyography (EMG) signal epoch of Patient 5 with negative myoclonus during the extension of wrists. The negative myoclonus segments found by the developed algorithm are marked with red rectangles.
Positive myoclonus was observed in EMG data as an alternating impulse pattern corresponding to repeating muscular discharges in concordance with previous findings (Avanzini et al., 2016). The myoclonus-related repeating muscular discharges were observed as an increased EMG spikiness ($k$), increased percentage of recurring patterns ($\%REC$) and decreased complexity ($D_f$). The decreased complexity and increased recurrence of neuromuscular function might be related to pathological exaggeration of physiological central rhythmicity related to movement that has been observed as an increased CMC in subjects with myoclonus (Caviness, 2007). It has been shown that EPM1 patients have higher CMC in the lower beta-band and it is less variable compared to healthy controls. Moreover, this synchronization is observed in larger cortical area compared to controls (Franceschetti et al., 2016) and correlates with the severity of myoclonus. We have observed a similar phenomenon of rhythmicity previously in patients with Parkinson’s disease (Rissanen et al., 2012). Acceleration signals showed an increased power of involuntary movements (increased $M_{ACC}$) meaning more myoclonic movements, with the peak power at around 3 Hz. Very little information is available in the literature about the kinematic frequencies of different myoclonus types. However, since the maximum value of the power spectrum at one frequency point correlates strongly and significantly with the myoclonus severity, it indicates that there is a characteristic frequency for myoclonus in EPM1. When compared with our previous study on parkinsonian tremor (Rissanen et al., 2012), the myoclonic jerks seemed to be less regular in kinematics and the myoclonic EMG spikes less synchronized in the EPM1 patients. Therefore, identifying myoclonic jerks from EMG and kinematic data from EPM1 patients appears to be both feasible and reliable.

Negative myoclonus was detected here in EMG data as a silent period for 50–150 ms preceding and following muscular activation in accordance with previous findings (Chen and Chen, 2020). The short losses of muscular tone during negative myoclonus do not always result in a visible loss of posture or in dropping of objects from hands. Therefore, they are difficult to detect, if only video- or motion-based sensor assessments without EMG are used. Negative myoclonus episodes can be difficult to detect and report by patients themselves. In this study, none of the patients reported episodes of negative myoclonus in the diaries. Therefore, the developed measurement and detection algorithm for negative myoclonus may help in obtaining objective, quantitative information about it. In further studies, negative myoclonus detection algorithm will be tested for a larger set of patient data. The number of negative myoclonus episodes and the duration of muscle tone loss will be counted from the home-measured data to assess correlations with disease severity.

The presence and degree of positive myoclonus varied during the day according to the monitoring data and patient symptom diaries in this study. Based on the $M_I$, almost all patients ($N = 22$) suffered from at least one positive myoclonus period during the evening (between 6–10 pm) and over 60% of patients suffered from myoclonus in the morning in concordance with the disease characteristics (Crespel et al., 2016). The monitoring-based $M_I$ increased often during daily activities, e.g., during eating lunch and dinner. In general, the myoclonus was less severe during the night. However, in 13 patients the $M_I$ increased, and the myoclonus appeared at least once in the middle of the night as well. Most of these myoclonus periods in the night were not reported by patients in their symptom diary. In this study, we did not find significant differences in the sum of $M_I$ per time unit between the first and the second day for neither of the muscles. Some patients had more myoclonus on, Day 1 and some on Day 2.

### 4. Discussion

This study showed that wearable EMG combined with 3D-accelerometry was a reliable and objective tool to detect both positive and negative myoclonus in EPM1 patients. To our knowledge, this was the first study employing this technique to detect negative myoclonus and to measure myoclonus fluctuation in EPM1 patients at home. The EMG- and ACC-based $M_I$ correlated strongly with myoclonus severity as evaluated using video-recorded UMRS, and moderately with patients’ self-reporting of degree of myoclonus at home.
important tools to collect information about a patient’s symptoms at home, but a few limitations are related to them. The self-evaluation of the degree of myoclonus is difficult because of the subjectivity of rating and because the reporting frequency cannot be too high to not burden the patient. In the current study, for example, only one value was reported per hour despite any fluctuation in the degree of myoclonus, and this reporting was already felt by many patients to be too demanding. The monitoring data, instead, gives numerous estimates on myoclonus every hour, and during sleep as well. Due to the challenges in reporting, we analyzed only changes in the self-reported degree of myoclonus; the unreported hours (10 ± 12 as mean ± SD) were left out of the correlation analysis. We used the mean parameter values of each hour for the correlation analysis, which may have reduced the strength of the correlation between the monitoring and the self-reported data. Another factor possibly affecting the correlation results was that patients were instructed to report on overall degree of myoclonus (not only in their arms), but the sensors were attached to their arms.

To obtain objective information about patient symptoms at home, in addition to symptom diaries, treating physicians require supporting tools to quantify patient symptoms during daily activities at home. Most of the systems suggested for the monitoring of movement disorders are based on sensors (Jalloul, 2018) or cameras. We have recently described a video-based motion tracking method for automatic quantification of myoclonus jerks in ten EPM1 patients during UMRS evaluation (Hyppönen et al., 2020). When compared with camera-based motion tracking, sensor-based systems can provide continuous data on movement disorders, without limitations, recording surroundings and daily activities. Small sensors are simple to attach, and they disturb a patient’s normal activities very mildly. In this study, 22 of 23 patients were
able to complete the 48-hour measurements from both arms successfully. One patient had to stop the measurement after 7.5 hours because of itchy skin. During the monitoring, no restrictions were imposed on patients’ daily activities or movement in different surroundings. Despite this, none of the monitoring data had to be excluded from analysis because of low quality, suggesting that wearable EMG with accelerometry is a promising tool for assessing real-life severity of myoclonus. The optimal number of sensors needed to capture all myoclonic periods is, however, unclear. Previously, an increase in the number of sensors did not result in improvement in the detection of tremor and dyskinesia in upper extremities (Lonini et al., 2018). We used two sensors, and both were able to detect myoclonic periods. The myoclonus index of the dominant BB correlated slightly better with the UMRS results than the index of the non-dominant EDC. Therefore, in the future biceps brachii might be selected as a target for both sides. It is possible that the stronger correlation for BB compared to EDC resulted partly from the higher activation level of BB during the finger-to-nose test.

In this study, we combined surface EMG with motion-based measurements and computed the parameter $MI$ based on both measurement techniques. The combination of these two techniques enables the cross-validation of findings, which helps in differentiating voluntary muscle contractions from involuntary muscle contractions, and voluntary movements or artefacts from myoclonic jerks. The computed $MI$, which was observed to correlate strongly with the UMRS, could be used in further studies to continuously measure and assess myoclonus in the home environment. Potentially, it could be used as a quantitative measure to support the evaluation of long-term drug effects in a clinical trial.

Myoclonus is also observed in a number of other epilepsy and movement disorders (Caviness, 2009). Electrophysiological characteristics of the myoclonic jerks are considered to be an important step during diagnostic evaluation (Zutt et al., 2015). In this study the protocol for EMG analysis was designed to detect the myoclonus with the duration typical for cortical- and cortical-subcortical origin (Avanzini et al., 2016; Caviness 2009). Therefore, this method might be useful for the detection and follow-up of myoclonus in other diseases showing cortical myoclonus such as other types of progressive myoclonic epilepsies and posthypoxic myoclonus (Caviness, 2009). Other types of myoclonus such as spinal or peripheral show different EMG-patterns (Zutt et al., 2015). For the evaluation of other than cortical-subcortical myoclonus types, the sampling of different muscles as well as the number of muscles should be adjusted to the specific clinical problem. Moreover, the adjustment and validation of the algorithm for the detection of myoclonus of specific length (e.g., for longer EMG burst duration), distribution and propagation should be performed. However, our method provides feasible potential to be adapted for the home-based diagnostic recordings and monitoring of myoclonus in other neurological disorders and also in the differential diagnostics of functional or psychogenic myoclonus.

In conclusion, ambulatory surface EMG and 3D-accelerometry with wearable sensors were able to detect both positive and negative myoclonus in EPM1 patients and objectively demonstrate fluctuations in the degree of myoclonus at home for 48 hours. EMG and ACC parameters correlated strongly or moderately with the clinical scores and patient symptom diaries. These measurements may be potential tools for quantifying real-life antmyoclonic treatment effects in formal clinical trials as well as after clinical interventions in individual patients. They will give us also new tools to unfold natural course and progression of diseases with myoclonus. A further cross-validation study with simultaneous video-based assessment for several hours will be performed.

**Declaration of Competing Interest**

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:
S.M.R. is a co-founder in Adamant Health Ltd that develops EMG-based analysis software.

J.H. Declarations of interest: none.
K.S. Declarations of interest: none.
L.S. Declarations of interest: none.
P.A.K. is a co-founder in Adamant Health Ltd.
E.M. Declarations of interest: none.
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