# Summary

Evaluation of symptoms in movement disorder patients generally implies subjective assessment based on observation. Furthermore, this clinical observation typically takes 30-60 minutes, giving only a glimpse of the condition of the patient and thereby an incomplete picture of the overall severity and impact of the disease.

Aiming to reduce the subjectivity involved in clinical assessment, researchers have developed clinical protocols, but even with these protocols, it has been suggested that proper evaluation of movement disorders patients remains a challenge. One way to further reduce subjectivity in the evaluation of symptoms is using clinical neurophysiological evaluation techniques. These techniques involve the use of instruments capable of measuring and recording signals from the human body, such as electromyography or accelerometry. The combination of clinical protocols with these techniques may present a key tool in the reduction of subjectivity for the assessment of symptoms in movement disorder patients.

In this thesis, we tried to improve upon the two issues reported in literature and well known to movement disorders experts and researchers: subjectivity in the assessment of symptoms and the typically limited duration of observation. By proposing the use of inertial sensors, we expected that both the clinical diagnostic work-up and long-term monitoring at home could be supported.

For diagnostic purposes, we aimed to improve upon the distinction between children with early onset ataxia (EOA) or developmental coordination disorder (DCD) and healthy children. The relevance of the distinction between EOA patients, DCD patients and healthy participants is that EOA and DCD patients share several clinical characteristics, such as poor coordination, unsteady gait and lack of balance. This overlap in clinical characteristics represents a major challenge in the distinction between these two groups. For our studies, we recruited patients and healthy aged-matched controls and asked them to execute different tasks from the SARA protocol while wearing inertial sensors.

In Chapter 2, we first studied whether the three kinetic upper limb tests (finger to nose, finger chasing and fast alternating movements) of the SARA protocol would perform better than just the single finger to nose test in distinguishing between the three groups of interest. Here, three IMUs were attached to the dominant upper arm, forearm, and wrist to obtain inertial data during test execution. Applying a Kalman filter, we created a model of the upper limb and obtained the position and orientation of the upper arm, forearm, and hand. From these three-dimensional positional data, by incorporating expert knowledge about ataxic movements, we mathematically derived objective measures related to e.g., curvature and velocity. We then used this information to distinguish between EOA and DCD patients and healthy participants using a random forest classifier. The results showed that the most relevant discerning features concerned smoothness

and velocity of movements, obtaining an overall classification accuracy of 85.8%. We concluded that combined information from all three SARA-kinetic upper limb tests improved the classification of all diagnostic groups, and in particular of the DCD group compared to using only the finger to nose test (73.7% accuracy).

In Chapter 3 we then used a similar approach to study classification results based on the (normal and tandem) gait tests in the SARA protocol. Participants were asked to execute these SARA tests with IMUs attached to the bilateral thighs and shanks. Then, using the obtained inertial data we implemented a mechanical model to reconstruct walking patterns and obtain spatial-temporal gait features. Also, we extracted statistical features from the linear acceleration and angular velocity signals to quantify the regularity of movement. We then used all those features to again distinguish between EOA and DCD patients and healthy participants using a random forest classifier. According to the classification results, the most relevant features were those representing variability of movement in normal and tandem gait and obtaining an overall mean classification accuracy of 82.0%. We then concluded that classification based on a combination of features representing variability of movement in normal and tandem gait, could be used as a support tool in the differential diagnosis of EOA and DCD.

In the second part of this thesis, we investigated the use of accelerometry for long term tremor recordings and its applicability for home-based tremor quantification. We asked organic and functional tremor patients to wear an IMU on the wrist of the most affected arm during daily activities and in the home environment for 30 days.

In Chapter 4, we used these inertial data to investigate the optimal number of days needed to obtain reliable estimates of tremor percentage, tremor frequency variability and tremor intensity during long-term recording. We choose those variables since they are commonly used to characterize tremor in tremor patients. To determine this minimal recording period that would still yield reliable data, first a tremor identification algorithm was used and tremor presence, frequency variability and intensity were calculated per day. We then used reliability analysis to determine the minimum number of days needed to obtain reliable estimates of these tremor characteristics. Our results indicated that using five hours per day, one day of measurement is enough, except for tremor frequency variability in organic tremor patients, where three days are needed and in the case of tremor intensity two days are always needed. Finally, we concluded that three days with at least three hours of tremor data provide estimates of tremor percentage, frequency variability and intensity with good to excellent reliability, both for organic and functional tremor.

In Chapter 5, these long-term tremor data were used to investigate the hypothesis that functional tremor patients overestimate tremor presence compared to organic tremor patients since patients with functional tremor were previously found to exhibit a large mismatch in objectively deter-

mined and self-reported tremor symptoms. To this end, subjective estimation of tremor presence obtained from web-based diaries completed five times per day by the participants, was compared to objective tremor presence estimation using the wrist IMU data and the tremor identification algorithm. Our results showed that patients with functional tremor had shorter objective tremor duration compared to patients with organic tremor. Furthermore, subjective symptom burden was not significantly different between functional and organic tremors. We concluded that functional tremor patients have a similar symptom burden and a similar association between subjective and objective tremor symptoms as patients with organic tremor.

Finally, in Chapter 6 we discussed more generally the work presented in this thesis, as well as the common challenges found throughout the different chapters. We focused our attention on the use of movement sensors as a support tool in the clinical evaluation of movement disorders, particularly for diagnosis and monitoring, that currently rely on clinical observation. In the diagnosis part, we concluded that the obtained results could be used for clinicians and researchers as additional information during the diagnosis of EOA, DCD or healthy participants. Furthermore, this information could also motivate researchers to do future research and clinical validation to create new clinical protocols, similar to the SARA protocol. For the monitoring part, we showed that long term recordings of tremor are of additional value for therapeutic (clinical) interventions. In conclusion, the results obtained in this thesis provide evidence that movement sensors can be used as a support tool for the monitoring and diagnosis of movement disorder patients.