Characters including spaces: 2999 (3000 character limit, including spaces)

Unravelling quantitative measures of free-living ataxic gait in cerebellar patients using wearable sensors

Winfried Ilg, Jens Seemann, Matthis Synofzik

BACKGROUND AND AIM: The characteristics of ataxic gait can be captured in a sensitive and specific fashion by spatio-temporal variability measures in laboratory examinations, allowing to quantify disease stages even at preclinical stages and to determine intervention-based improvements. Identification of ecologically meaningful improvements, however, requires quantification of patients' motor behavior during everyday life. Yet transfer of laboratory-based measures of spatio-temporal step variability into free-living is complicated by that fact that free-living gait is inherently far more variable. Moreover, patients may use various compensation strategies, thus increasing the heterogeneity of walking patterns. Here, we aimed to unravel measures that allow to quantify the specificities of ataxic gait in free living by wearable sensors.

METHODS: We assessed gait features of 20 patients with degenerative cerebellar disease (age: 52±15, ataxia score SARA: 10.2±2.9) compared to 10 age-matched controls by 3 inertial sensors (Opal, APDM) attached to the feet and the lower back in two conditions: (i) The *constrained* condition assessed straight walking in a clinical setting with slow and normal speed each for 1 minute, allowing to establish characteristic features of ataxic gait; (ii) the *unconstrained walking condition* assessed at home, capturing 4-8 hours of free-living gait (subset: 5 patients, 5 controls), allowing to test whether features established in the constrained condition can also be identified in free-living gait. Therefore, we extracted walking bouts with 10 subsequent strides within a limited speed range, resulting in 900-2000 gait cycles. Analysis included a compound measure of spatial step variability consisting of lateral step deviation and step length variability.

RESULTS: The constrained walking condition allowed to identify group differences in step length variability ($p<0.005$), lateral step deviation ($p<0.01$) and the compound measure of step variability ($p<0.001$) for slow and normal walk, with step variability correlating with ataxia severity (SARA, $p=0.03$). This compound measure of step variability was also re-identified in the unconstrained free-living condition, demonstrating a group difference ($p=0.03$) and showing a strong tendency towards correlation with ataxia severity ($r=0.86$). Moreover, step variability during unconstrained walking (filtered for walking bouts within the speed range of constrained walking) correlated with step variability during constrained walking ($r=0.93$, $p=0.03$), indicating validity of this measure across conditions.

CONCLUSIONS: This study unravels quantitative measures that allow to quantify the characteristics of ataxic gait in free-living, using wearable sensors. In particular, the compound measure of spatial step variability can be extended from constrained to free-living gait, both times reflecting disease severity, thus yielding a promising outcome measure for natural history and treatment trials.

Acknowledgements:
This project was supported by the German Hereditary Ataxia Society (DHAG) and the Stiftung für Hoffnung.