

BACKGROUND

Freezing of gait (FOG) and falls in Parkinson's disease (PD) are generally thought to be closely related; both occur sporadically, are often resistant to dopaminergic treatment, and greatly diminish quality of life. Recent laboratory studies have demonstrated high-frequency components (2-6 Hz) in insole pressure during FOG, which may be preceded by higher stride-to-stride variability (Hausdorff et al. 2003). To date there is no objective measure of FOG and subsequent falls outside of the laboratory.

METHODS



Fig. 1. Ambulatory gait monitor, consisting of an IMU, bluetooth transmitter and battery.

We conducted a pilot study (N=10; 8 males) of ambulatory freeze monitoring. All patients had advanced PD (H&Y III-IV when 'off') and a clinical history of FOG, and were prescribed oral levodopa (LD). Subjects arrived in the morning in an 'off' state (no PD medication in the past 12 hours) and walked for a maximum length of 100 m about a series of internal hallways. They then took their usual morning dose of oral levodopa and repeated the walking task approximately every 15 min over a 90 min period. Walking trials were recorded using a digital video camera and FOG and standing events identified *post-hoc* by a movement disorders specialist. Patients wore a lightweight (130 grams) gait monitor (Fig. 1) on the left leg (Moore et al. 2006), which measured vertical acceleration of the shank (as well as sagittal angular velocity for determining stride length).

RESULTS

Six subjects experienced a total of 44 FOG events (range 3 -17 per subject, mean 7.3 [SD 5.1]); 4 subjects did not freeze. FOG occurred during gait initiation (14), or interrupted locomotor activity when turning or encountering an obstacle (doorways, moving around furniture etc, 30 events). Almost half (40%) of FOG events occurred prior to LD administration (Fig. 2), and a cumulative total of 82% occurred within 40 minutes post-LD. During FOG, high-frequency components (2-8 Hz) were present in the vertical acceleration of the shank that were not apparent during quiet stance (Fig. 3). The power in this 'freeze' band was significantly larger during FOG when turning or encountering an obstacle relative to FOG events when initiating gait, and the power spectra during FOG were significantly larger than when quietly standing (Fig. 4). A simple freeze index (FI) at time *t* was defined as the area under the power spectra of a 5 s window of data (centered at time *t*) in the 'freeze' band (3-8 Hz), divided by the area under the spectra in the 'locomotor' band (0.5-3 Hz) (Fig. 5). This was done to minimize the influence of high frequency harmonics (> 2 Hz) during walking on freeze

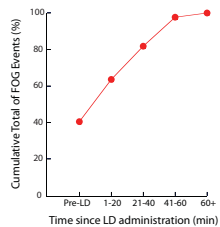


Fig. 2. Cumulative total of FOG events as a function of time (min) since LD administration.

detection. FI was a dimensionless, continuous value (Fig. 5; lower panels - red trace) and scaled such that the largest value encountered was set to 100. During FOG, peak FI ranged from 0.05 to 100 (N=6; mean 7.2 [SD 20.2]), and was larger ($p=0.03$) than peak FI during periods of quiet standing (N=10; range 0.01-1.6; mean 0.12 [SD 0.3]). A global threshold was chosen at 0.1 such that an FI of equal or greater value was defined as a freeze event. As shown in Fig. 5a, the FI detected most FOG. Of the 44 FOG events, 34 (77.3%) were detected. Of the 46 periods of standing (i.e., intentional, not FOG) from the 10 subjects, 9 (19.6%) were erroneously marked as FOG. However, establishing an individual FI threshold for each subject significantly improved accuracy and sensitivity of the freeze monitor. The individual threshold ranged from 0.1 to 0.8 (N=10; mean 0.22 [SD 0.23]), and increased FOG detection to 39 of the 44 events (88.6%) and decreased false positives to 5 of 46 stand events (10.9%).

Power spectra of vertical leg movement during FOG

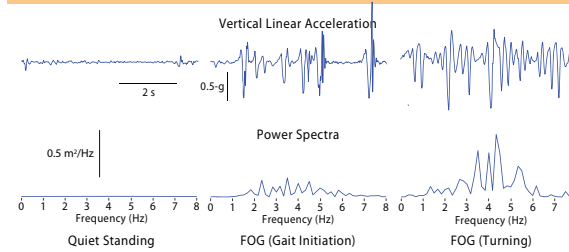


Fig. 3. Vertical linear acceleration (6 s of data) of the left shank in a patient with advanced PD (top row), and power spectra of shank acceleration (bottom row). Note the appearance of high-frequency components (2-8 Hz) during freezing.

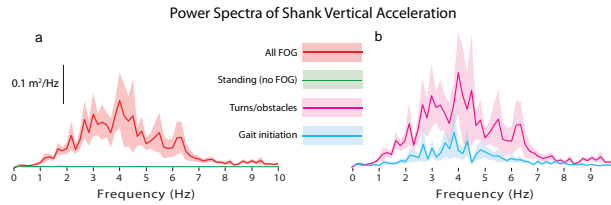


Fig. 4. a Power spectra (mean and SEM) of all 44 FOG events from 6 patients (red trace) and from 46 periods (all 10 patients) of quiet standing (green trace). b The FOG mean power spectra during gait initiation (14 events; blue trace) was significantly smaller than for FOG events during turning or encountering an obstacle (30 events; magenta trace).

Autonomous detection of FOG from power spectra

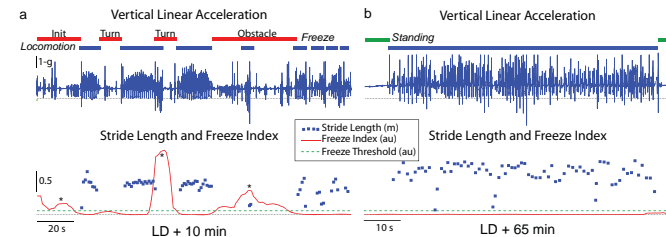


Fig 5. Freeze detection in a subject with advanced PD. Red bars above vertical acceleration trace – FOG events; Blue bars – locomotor activity; Green bars – quiet standing. a Ten minutes post-levodopa (LD) administration. The subject had 4 FOG events, as determined from video recordings. A global freeze threshold of 0.1 (green dashed line, lower trace) for the freeze index (FI – red trace) detected 3 FOG events, indicated by * (note FI and threshold are in arbitrary units). Determining an individual threshold for this subject resulted in all 4 FOG events being detected. b Almost one hour later the subject is walking freely with no FOG. Note that FI can discriminate between periods of standing and FOG.

CONCLUSION

The results from this study demonstrate the feasibility of ambulatory freeze monitoring in advanced PD.

Hausdorff JM, Balash Y, Giladi N (2003) Time series analysis of leg movements during freezing of gait in Parkinson's disease: rhyme or reason? *Physica A* 321: 565-570

Moore ST, MacDougall H, Gracies J-M, Cohen H, Ondo W (2006) Long-term monitoring of gait in Parkinson's Disease. *Gait Posture* doi:10.1016/j.gaitpost.2006.09.011