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Quantitative assessment of driving performance in Parkinson's disease (PD) with and without medication or subthalamic nucleus (STN) stimulation

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INTRO.

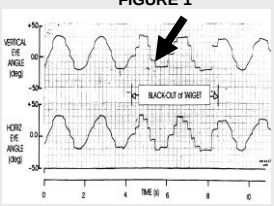
Driving a car is an essential everyday coordination task. The many symptoms of idiopathic parkinson´s disease (PD) span from narrowed attention/ slowed cognition with prolonged sensory-motor latencies to the characteristic motor abnormalities of tremor, rigidity, slowness and hypometria of the patients´ movements.

In vision during smooth pursuit the target is fixed on to the fovea as the eyes track the slowly moving target with velocities < 30°/sec, even though the eyes are moving. Internal model information reinforced by efferent copy information regarding eye position and velocity allows the subject to be aware of the motion of the target even though there is no or negligible retinal slip.

During driving, Smooth Pursuit Eye movements appear as dynamic Fixations on to moving targets. Fig.1 shows the *Dual Mode Control of Eye Movement Tracking*, i.e. the ability of **Dynamic Fixation during smooth pursuit,-** and also the Saccadic Degradation of Dynamic Fixation in case of a lost target (arrow).

PD patients show inaccurate static and dynamic fixations during driving with consecutive loss of targets and delay of their reactions.

FIGURE 1



METHODS.

Using an infrared camera system (GazeTracker) that allowed completely free head-eye movements within a driving simulator we recorded eye-head-gaze-coordination as well as steering, indicator and accelerator/ brake signals from our 20 PD patients (mean age 63.6 , 4 females) and 20 normal age matched subjects. PD symptoms were graded according to: UPDRS pt.1-4, Hoehn & Yahr, MMST and Demtect. Average duration of PD symptoms was 5 years (stdev. +- 0.8y.). All patients were on dopaminergic medication; all were treated with an implanted **STN stimulator (Fig.2)**: patients that suffered from vertigo and syncopes were excluded. After some basic oculomotor checks, and after 5 minutes of practicing with the simulator driving system, they had to drive for five minutes through an unknown realistic course with STN stimulation ON, and after a short pause with STN stim. OFF. In European car driving schools, this kind of simulator course is commonly used for training and testing (Bessier Software: 3d driving school) The time series data of gaze-steering-acceleration/brake driving control were analyzed (Autosignal 1.52) using first a fast fourier analysis (FFT) the Prony Spectrum option, and then Parametric Interpolation and Prediction. Statistical data analysis was performed with the "Statistika" program; we used Student's t-test for group comparisons, or in case there was no normal distribution, we used the Mann-Whitney rank sum test. For the calculation of correlations we used the Pearson product moment value.

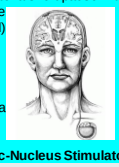


Fig.2: Sub-Thalamic-Nucleus Stimulator

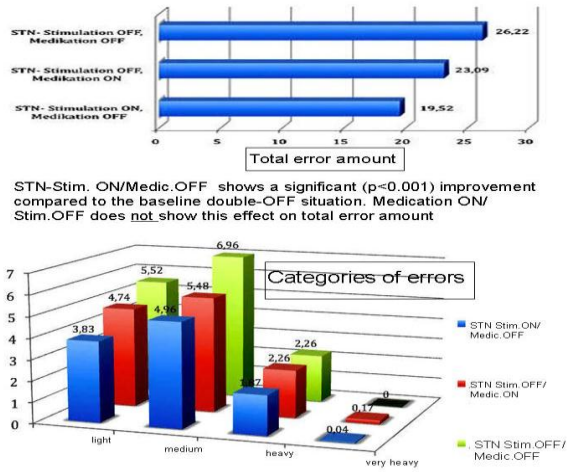
RESULTS

Table 1 lists typical driving errors of the PD patients; Tab.2 gives the overall driving score and types of driving errors made by the two groups,and within the PD group under medication or STN-Stim. only.

	Participant groups		Statistics	
Driving scores	Controls	Parkinson's	t Value	p Value
Overall score %	83.95 (1.61)	77.18 (2.15)	2.43	0.02
Critical errors	0.38 (0.17)	1.12 (0.36)	−1.75	0.09
Observation errors	3.14 (0.63)	5.04 (0.93)	−1.62	0.11
Blind spot errors	5.19 (0.66)	7.52 (0.74)	−2.30	0.03
Indicator errors	6.09 (0.58)	6.80 (0.77)	−0.71	0.48
Brake/accelerator errors	8.19 (1.26)	9.80 (1.76)	−0.72	0.48
Lane keeping errors	4.62 (1.00)	10.20 (1.62)	−2.80	0.01
Gap selection errors	3.62 (0.60)	4.40 (0.63)	−0.89	0.38
Approach errors	8.28 (1.24)	10.36 (1.57)	−1.00	0.32
Directed errors	27.14 (3.64)	38.60 (4.40)	−1.96	0.06
Self directed errors	12.00 (1.89)	15.52 (2.26)	−1.17	0.25

Values are mean (SD).

FIGURE 3



RESULTS: TWO EXAMPLES

Figures 4 to 5 show examples of basic deficits of one typical PD patient with STN Off and On. On left side of each panel time course of braking (red), accelerating (blue), and steering wheel (green) are depicted.

Brake Accelerator Steering Wheel

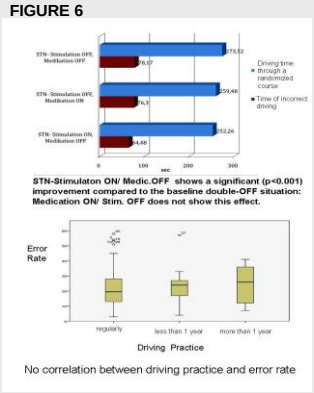
FIGURE 4

PD patient, **STN Off**, after leaving roundabout: Steering control begins too late & too weak, with consequence of crossing to opposite lane without any correction; too strong and simul-saneous control of acceleration & brake,Gaze fixation to midline

FIGURE 5

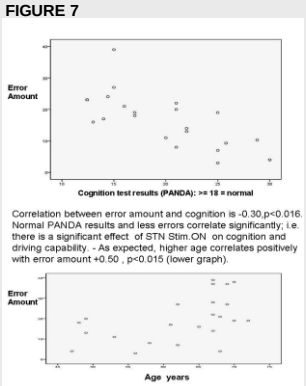
PD Patient, **STN On**, after leaving roundabout: Steering control correct, driving correctly in right lane; only one correction of steering. Corrections of brake & acceleration are not necessary; correct gaze orientation towards the distant center of the road.

FIGURE 6



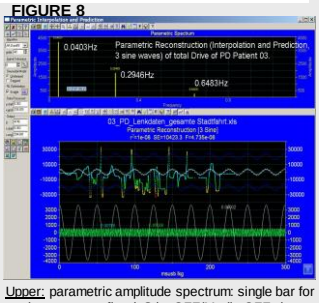
No correlation between driving practice and error rate

FIGURE 7



Correlation between error amount and cognition is -0.30,p<0.016. Normal PANDA results and less errors correlate significantly; i.e. there is a significant effect of STN Stim.ON on cognition and driving capability. - As expected, higher age correlates positively with error amount +0.50 , p<0.015 (lower graph).

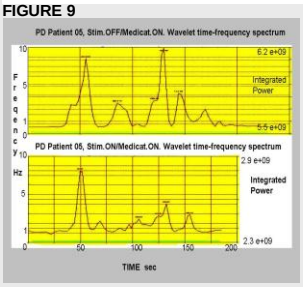
FIGURE 8



Upper: parametric amplitude spectrum: single bar for each component fitted. Stim.OFF/Medic.OFF shows high amplitude/low frequency sinusoid components: 0.040, 0.294, 0.648 resp.; Stim.ON/Medic.ON shows low amplitude/ high frequency components: 0.408, 0.765, 1.538Hz resp.

Lower: non-linear optimization graph for data consisting of three sinusoids and noise. The three component functions are shown in the Y-axis plot. The Y2 plot contains the fitted curve and the data that were fitted. Parametric model (the fitted curve) is white and the data points are colored by relation to the fit standard error SE<1 cyan;<2green;<3yellow.

FIGURE 9



The Continuous Wavelet Transform (CWT) is used to decompose a signal into wavelets, small oscillations that are highly localized in time. The CWT constructs a time-frequency representation of a signal that offers very good time and frequency localization. Comparison of Medic.ON without(1) and with Stim.(2) shows similar but more variant frequency content and prolonged driving time in(1), double integrated power in (1), and a high frequency peak in(1) at 130 sec – the time of driving through the roundabout.

CONCLUSION I

On total error amount, STN-Stim.ON/Medic.OFF showed a significant improvement compared to the baseline double-OFF-situation. Medication ON/ Stim.OFF did not show this effect..- For light & medium errors both Medic.ON or Stim.ON showed significant improvement, with significantly higher improvement in Stim.ON.- For total driving time and errors/time, STN-Stimulaton ON/ Medic.OFF showed significant improvement compared to the baseline double-OFFand STN-Stimulaton OFF/ Medic.ON situation, which did NOT show this effect.- There was NO correlation between driving practice and error rate. Correlation between Cognition and Error amount was -0.30,p<0.016. **i.e. there is a significant effect of STN Stim.ON on cognition and driving capability in addition to Medic.ON**. - As expected, higher age correlates positively with error amount +0.50 , p<0.015.

CONCLUSION II. Our main result was the objective description of the recorded interdependent signals´ decay with respect to driving perforrmance as a function of ON versus OFF STN stimulation,- besides symptom-expression, disease duration and drug therapy. The special role of gaze-arm-foot coordination together with the narrowing of "attention" as a single, most important part of the disease progress, has so far not been realized by most clinical researchers. **Our recordings demonstrate the motor & cognitive improvement during a complex attention-coordination task through the ON-STN condition – in addition to the medication effect**. We conclude that Parkinson patients´ driving capabilities must be checked very thoroughly during the course of their illness, to avoid predictable traffic accidents.