SENSORS FOR MEASUREMENT OF TREMOR TYPE JOINT MOVEMENTS

Samo Ribarič[1] and Janez Rozman[2]

[1] Institute of Pathophysiology, Faculty of Medicine, Ljubljana, Slovenia
[2] ITIS d.o.o. Ljubljana, Center for Implantable Technology and Sensors, Ljubljana, Slovenia

Key words: tremor; Parkinson's disease, joint movement, apomorphine, sensor

Abstract: We developed sensors for measurement of the angle of joint deflection in tremor type joint movements. Two hand tremor measuring configurations that measure hand tremor amplitude with reference to the joint involved in tremor movement were evaluated. The shape of tremor sensors could be adapted to fit the contour of a specific joint. This modification did not degrade the sensor's sensitivity or dynamic range. We conclude that this method reduces between-subjects and within-subject variability of hand tremor measurements and also locates the hand muscle groups that are most active in tremor movement thus enabling their local treatment.

Tipala za merjenje s tremorjem povzročenih gibov v sklepih

Ključne besede: tremor, Parkinsonova bolezen, gib v sklepu, apomorfin, tipalo

Izvleček: Razvili smo tipala za merjenje kota upogiba v sklepih okončin, ki ga povzroča tremor. Z meritvami tremorja v zapestju in v prstu smo preverili delovanje dveh merilnih sistemov, ki sta bila opremljena z omenjenimi tipali. Obliko in velikost merilnih sistemov smo prilagodili ergonomiji merjenega sklepa. Taka prilagoditev ni omejila občutljivosti in merilnega območja tipal. Zaključujemo, da predstavljena metoda za merjenje tremorja, v primerjavi z obstoječimi metodami, zmanjšuje variabilnost meritev tremorja roke in olajša določitev mišičnih skupin, ki so najbolj aktivne pri tremorju okončine.

1 Introduction

Tremor is a rhythmic, involuntary oscillatory movement of a body part /1/. It is characterized by tremor amplitude and frequency. Identification of a specific type of tremor requires tremor amplitude assessment during different states of the body; during rest, active movement and posture of the affected body part. With the exception of primary orthostatic tremor, tremor frequency cannot determine the type of tremor since the frequencies of many tremor types overlap. Tremor can be assessed with a variety of techniques including clinical rating scales /2,3/, multichannel calibrated accelerometry /4/, electromyography /5/, multidimensional electromagnetic systems /6,7/, video image processing /8,9/, spirography /10/ and functional performance tests /11/. Clinical rating scales for example, Unified Parkinson's Disease Rating Scale (UPDRS) or Tremor Research Group Rating Scale (TRGRS), are still the most commonly used methods for tremor assessment in the clinical setting /12/. On the one hand clinical rating scales are only semi quantitative and prone to interobserver variability, but on the other instrumental measurement methods are complex, often unavailable for ambulatory patient assessment and adapted for a specific type of tremor /12/. Instrumental methods enable an accurate (0.1 mm amplitude resolution and frequency accuracy of 0.1 Hz) /6,9/ and long term tremor assessment (24 hours or more) /4/ but still measure tremor amplitude in the same way as clinical rating scales - by measuring displacement of a body part without reference to the joint movement that is responsible for tremor movement.

All healthy people experience some normal, transient tremor during their lifetime. The most common disease related (pathological) tremors are drug induced tremor, parkinsonian tremor and tremor associated with multiple sclerosis. Parkinson's disease (PD) is a progressive degenerative disorder of the central nervous system with tremor being one of its four main features /13/. Tremor is usually contributed to Parkinson's disease (PD) if the patient has any form of pathological tremor and fulfils the UK brain bank criteria for PD /14/. Rest tremor is the most common form of tremor in PD and appears in 80-90% of PD patients. The tremor of PD is usually asymmetrical, usually starting in the fingers of one hand and spreading proximally to the wrist and forearm /15/. PD patients experience a considerable variation in tremor amplitude in time, but a patient's tremor frequency is constant. Tremor frequency in PD patients ranges from 3 to 11 Hz, but is usually between 4 Hz to 6 Hz /1/.

Dopamine replacement therapy is the most common form of PD treatment. Apomorphine is used for testing patient responsiveness to dopamine replacement therapy (apomorphine test) and for treatment of patients with advanced PD /16/. Since PD is a progressive, chronic disease, the patient's medical condition has to be regularly monitored to achieve a best possible balance between an attenuation of PD clinical signs (*e.g.* tremor) and symptoms and drug side effects. Local treatment of PD tremor, for example hand tremor, can be achieved with botulinum toxin injections /17/. This type of treatment is possible only if the muscles that contribute most to tremor movement are identified.

The objective of this study was to develop a method for hand tremor measurements in ambulatory patients with PD. To achieve this objective we tested two hand tremor measuring configurations and evaluated rest tremor in PD patients before and after treatment with apomorphine, a dopaminergic agonist.

2 Methods

Two methods were used to attach the sensors to the hand - configurations 1 and 2. In configuration 1, one end of the sensor was mounted on a rigid glove and the second end rested on a steel ring (Figure 1). The glove was made of a non-toxic, non-allergic epoxy resin for medical use. Sensors were attached to the glove with brass screws and were positioned over the steel ring with aluminum spacers (Figure 2). In configuration 2, sensors were placed directly over the measured joints and secured to the skin with a strong waterproof adhesive tape (Figure 3). Tremor sensors were designed and developed by research company ITIS d.o.o. Ljubljana, Slovenia. Each sensor was essentially a complete Wheatstone bridge consisting of four force transducers glued onto a stainless steel strip. Technical details of both sensors are summarized in Table 1.

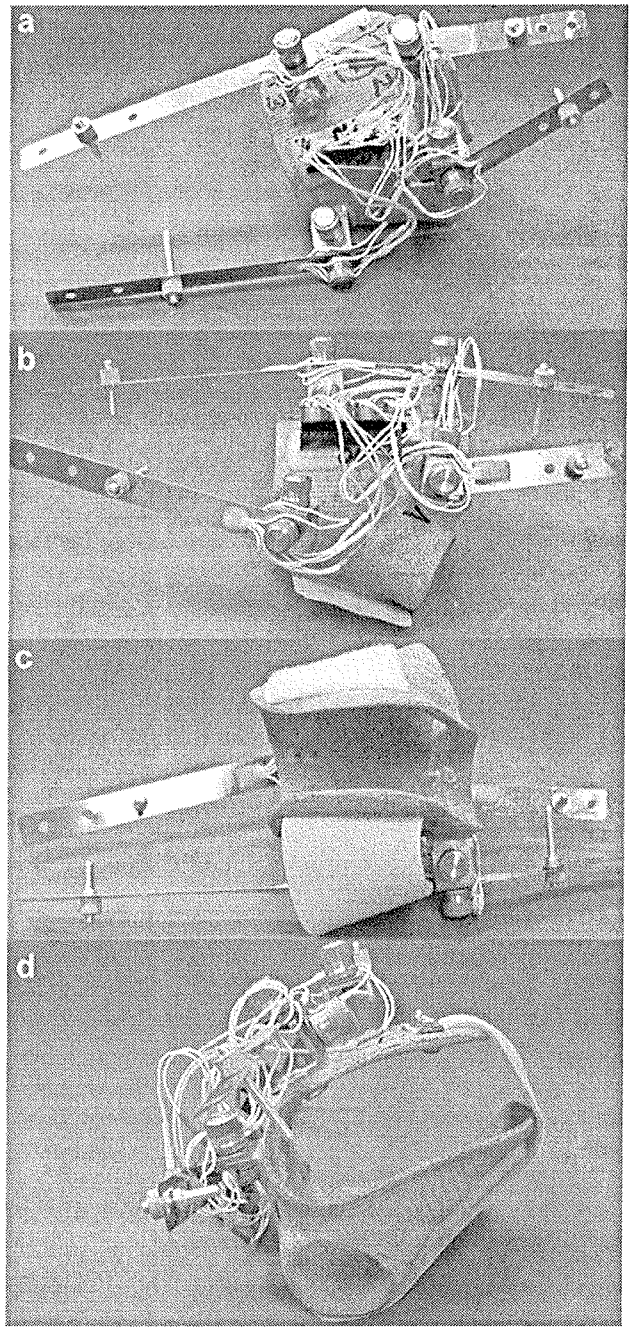

Fig. 1: Hand tremor sensor configuration 1 in four views top view (a), side views (b,c) and front view(d).

Table 1: Technical characteristics of sensors type 1 and type 2.

	type 1	type 2
sensor type	full Wheatstone bridge consisting of four force transducers	full Wheatstone bridge consisting of four force transducers
sensor material	semiconductive material	metal foil
manufacturer	Celesco, USA	Hottinger Baldwin Messtechnik GMBH, Germany
product code	P05-02-500	1-LY41-10/700
nominal resistance	500 Ω	700 Ω ± 0,3 %
conversion factor	≈ 10	2,08 ±1 %
glue for attachemnet to the steel support	Micromeasurements, USA M-bond 610	Hottinger Baldwin Messtechnik GMBH, Germany EP 250

The shape and size of tremor sensors was adjusted to fit the joint contour. Such alterations changed their mechanical properties (voltage output and resonance frequency) and required the sensors to be calibrated individually. Sensors in configuration 1 were of two types; a pair of shorter sensors for finger tremor measurement (sensors type 1A) and a second pair of longer sensors for recording wrist joint movement (sensors type 1B). In configuration 2 three sensors were essentially equal in size, shape and technical characteristics (sensors type 2B); the shape of the sensor that measured flexion-extension in the MCP joint (sensor type 2A) was adapted to fit the joint contour (top panel in Figure 2). Sensors type 1 and 2 were calibrated when mounted on the hand.

Tremor induced voltage changes in sensors were amplified by a custom designed bridge amplifier and stored on an IBM compatible PC. Analogue to digital (AD) conversion of force transducer signals (sampling rate 100 Hz) was performed by a 16-bit National Instruments data acquisition card PCI 6036e (National Instruments Corporation, Austin, TX, USA) with a voltage input range of ± 10 V. To determine sensitivity of the measuring setups we measured the common noise for type 1 and type 2 sensors.

We measured the angle of joint deflection in two degrees of freedom; during flexion-extension and abduction-adduction in wrist joint and metacarpophalangeal joint (MCP) of the 2. (index) finger. Therefore four sensors were used to measure rest tremor in each hand. Tremor sensors were

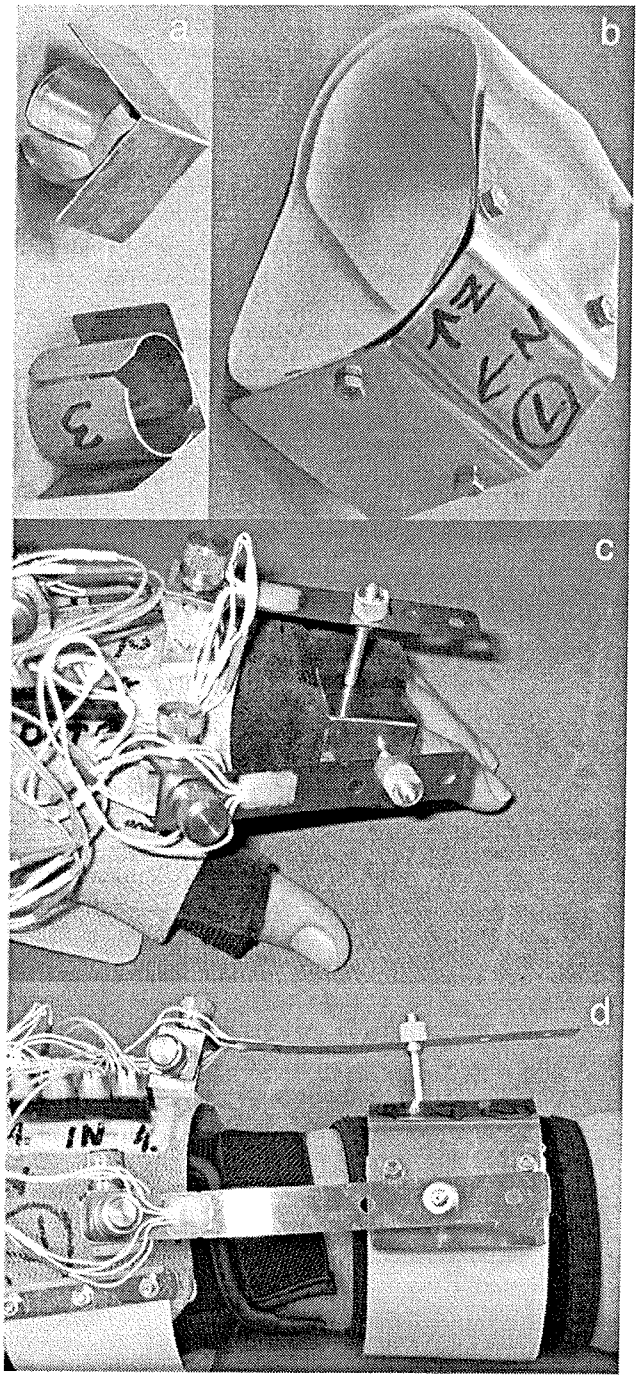

Fig. 2: Details of hand tremor sensor configuration 1: (a) steel ring for support of sensor S_{1A}, (b) steel ring for support of tremor sensor S_{1B}, close-up views of mounted tremor sensor type S_{1A}, (c) and tremor sensor type S_{1B} (d).

attached at predefined sites over the wrist and MCP joints of patients with PD. The sensor's location was inspected visually so that the sensors at the same joint were perpendicular to each other. We evaluated rest hand tremor in 5 PD patients before and after application of a tremor reducing drug (i.e. apomorphine (APO)). Only hand tremors with frequencies between 3 and 11 Hz were considered to be associated with PD /1/. An informed written consent was obtained from each patient. Patients were advised that they

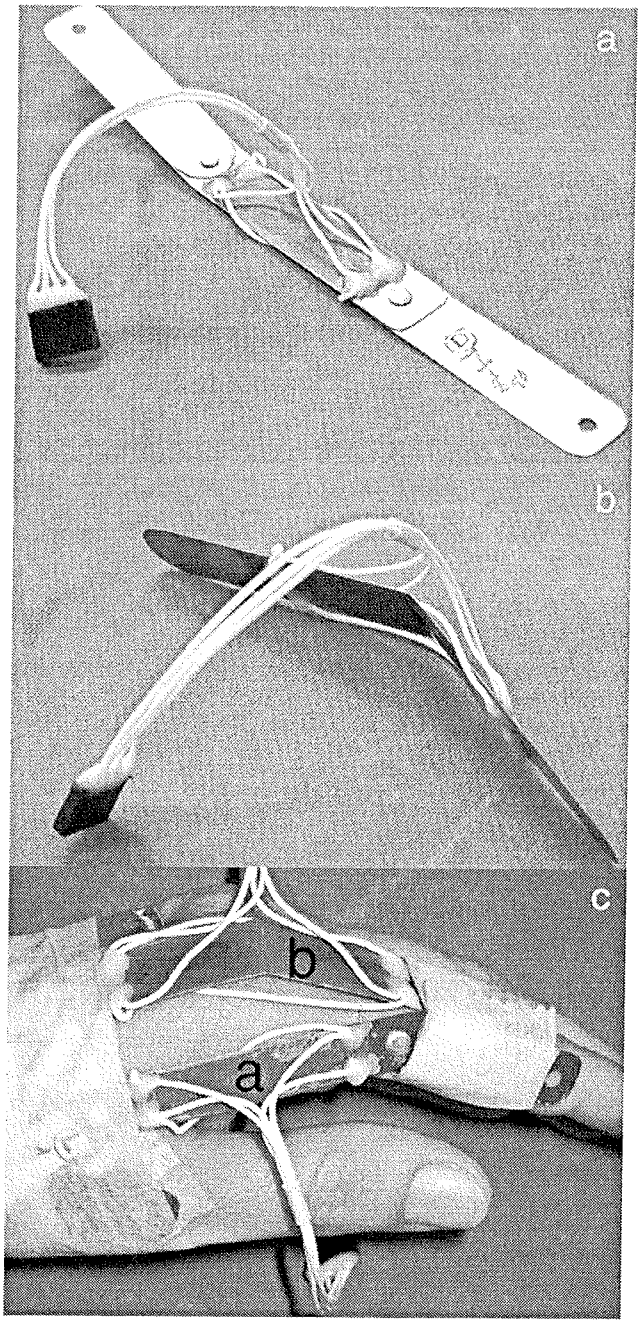

Fig. 3: Hand tremor sensors S_{2B} (a) and S_{2A} (b) in configuration 2 (c).

were free to terminate the measurements at any time, should they experience any discomfort. The study protocol was approved by the National Medical Ethics Committee of Slovenia and is in accordance with the Helsinki Declaration of 1975.

3 Results

A sensor's resonance frequency also depends on the sensor's size and shape. The resonance frequencies of sensors 1A, 1B, 2A and 2B range from 15 Hz to 47 Hz (Figure 4).

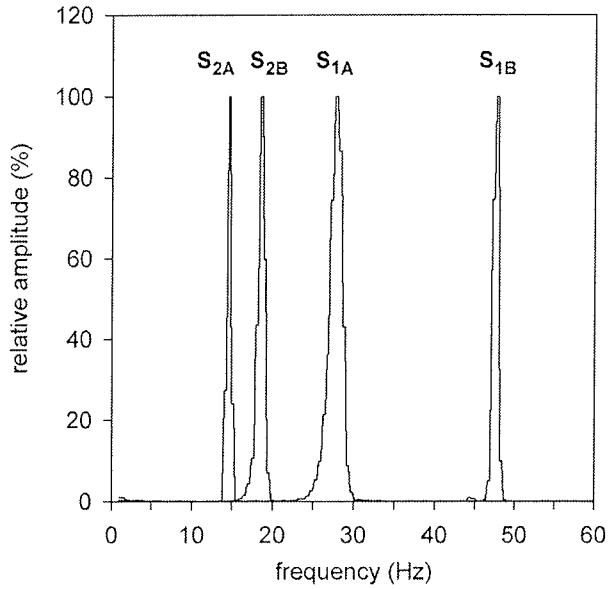

Fig. 4: Resonance frequencies of hand tremor sensors S_{1A}, S_{1B}, S_{2A} and S_{2B}.

The average common noise (five recordings) of sensors in configuration 1 and 2 is presented in Figure 5. Common noise amplitude was below 0.001 V.

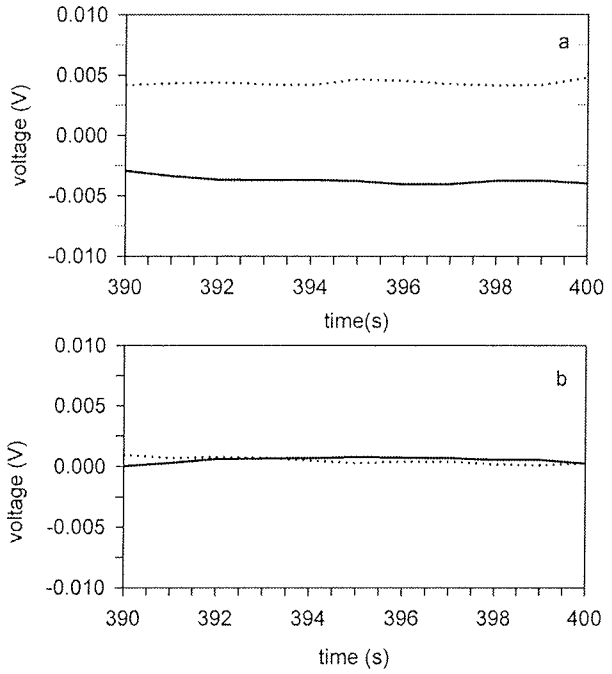

Fig. 5: Average common noise of tremor sensors 1: dotted line S_{1A}, straight line S_{1B} (a) and tremor sensors 2: dotted line S_{2A}, straight line S_{2B} (b). Each record represents an average of five measurements.

The voltage change (average of five successive measurements) in tremor sensors 1A, 1B, 2A and 2B, relative to an angle of joint deflection, is presented in Figure 6. Quadratic correlation between the angle of joint deflection and the corresponding voltage output of tremor sensors type

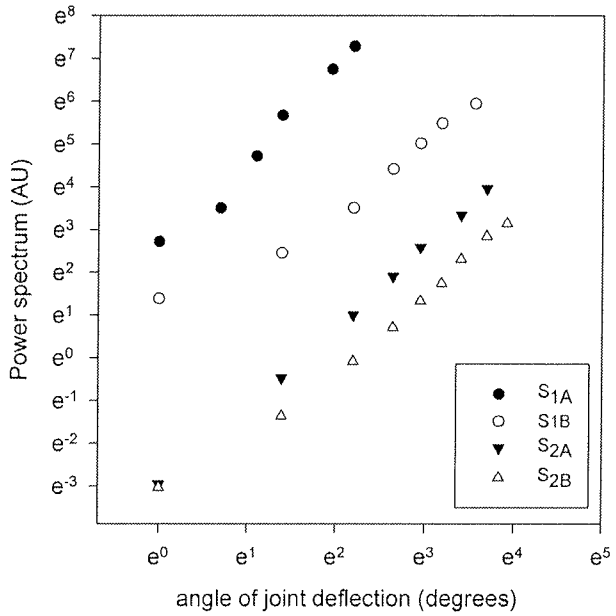

Fig. 6: Relationship between the angles of deflection and power spectra for hand tremor sensors S_{1A}, S_{1B}, S_{2A} and S_{2B}.

1 and type 2 was established by a series of joint deflections from 0.1^0 to 50^0 (Table 2).

Table 2: Quadratic curve fit of voltage changes at defined angles of joint deflection for sensors S_{1A}, S_{1B}, S_{2A} and S_{2B}. R^2 is the relative predictive power of the quadratic curve fit model. P values are the probability values that the sensors' data do not fit the quadratic curve fit model.

	$y = \beta_0 + \beta_1 x + \beta_2 x^2$				
sensor	β_0	β_1	β_2	R^2	P
S_{1A}	-6.184	-10.949	19.362	0.999	<0.001
S_{1B}	-11.829	5.047	0.188	0.990	<0.001
S_{2A}	0.039	0.034	0.032	0.998	<0.001
S_{2B}	-0.261	0.079	0.008	0.994	<0.001

Congruence between the observed hand tremor amplitude and calculated hand tremor amplitude (calculated from power spectra of tremor induced voltage changes) was evaluated by simultaneous visual and instrumental measurements of wrist hand tremor in 5 patients with PD. The results of this evaluation are presented in Figure 7. The observed and calculated TRGRS (calculated from power spectra of tremor sensor voltage changes due to wrist joint movement) were in a perfect linear correlation (R^2=1).

A typical example of a time course of hand tremor amplitude in the wrist joint and finger joint after APO application is shown in Figure 8.

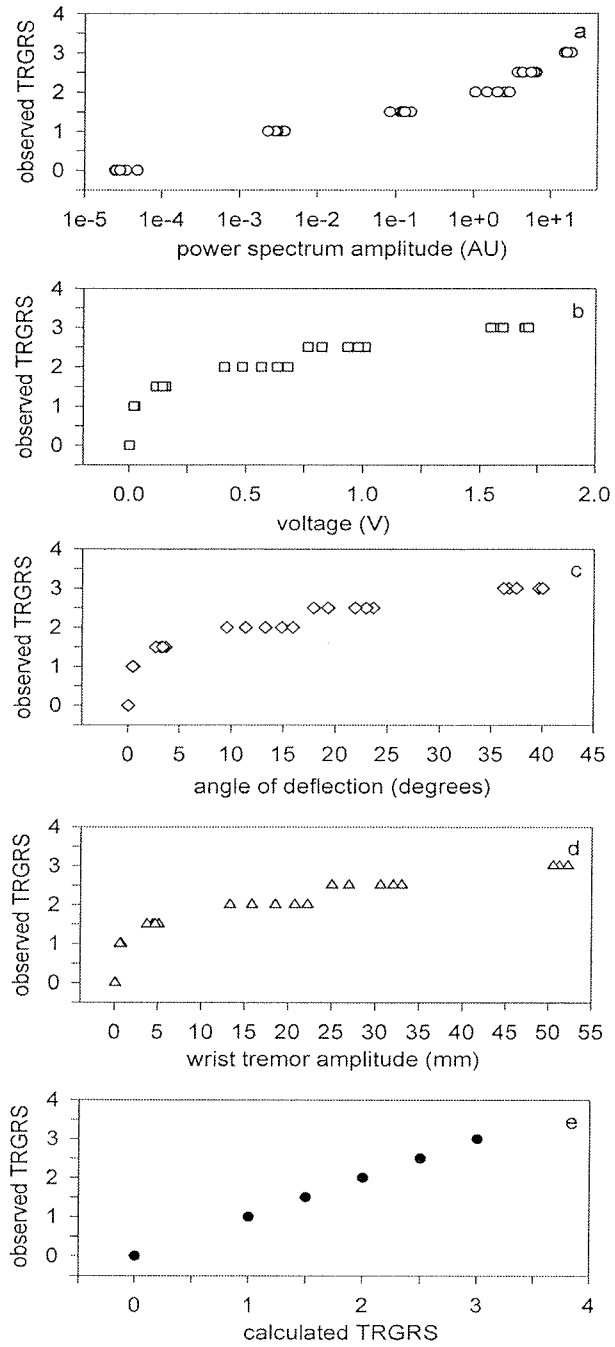

Fig. 7: Relationship among the observed TRGRS and calculated power spectrum amplitude (a), tremor induced voltage change (b), angle of wrist joint deflection (c), wrist tremor amplitude (d) and calculated TRGRS (e) in five patients with Parkinson's disease. The observed and calculated TRGRS (calculated from power spectra of tremor sensor voltage changes due to wrist joint movement) are in a perfect linear correlation. TRGRS scale: 0 = tremor not observed on visual inspection, 1 = tremor barely observed; 1.5 = tremor amplitude below 10 mm; 2 = tremor amplitude 10 - 29 mm; 2.5 = tremor amplitude 30 - 49 mm; 3 = tremor amplitude 50 - 99 mm; 3.5 = tremor amplitude 100 - 199 mm.

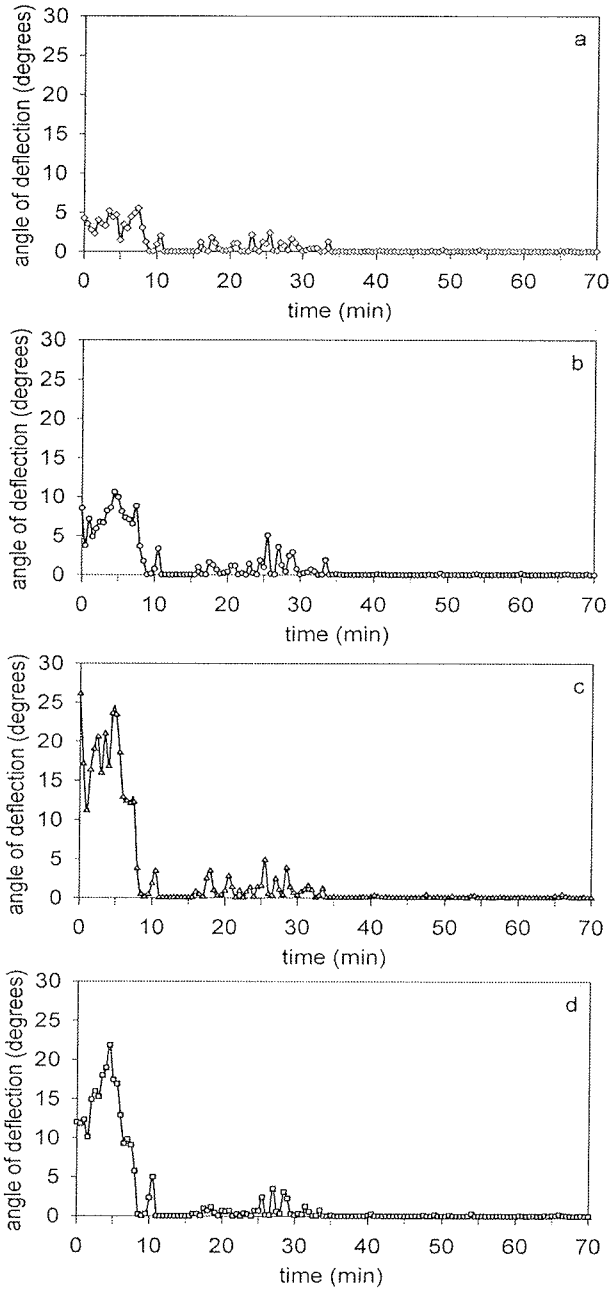

Fig. 8: Time course of hand tremor amplitude of a patient with PD after application of the tremor reducing drug APO. The angle of deflection was measured: in the metacarpophalangeal joint of the index finger (flexion-extension in graph a; abduction-adduction in graph b) and in the wrist joint (flexion-extension in graph c; abduction-adduction in graph d). Each data point on graphs a to d represents an average angle of deflection during a 30 s time window. The patient received APO at t = 0 min.

4 Discussion

We developed and tested two hand tremor measuring configurations (1 and 2) that measure hand tremor amplitude

with reference to the joint involved in tremor movement, thus reducing between-subjects and within-subject variability of hand tremor measurements. Tremor sensors in configuration 1 had a higher resonance frequency than in configuration 2. Therefore configuration 1 sensors can measure all types of tremor including primary orthostatic tremor with a frequency of up to 20 Hz /1/. The average rest tremor frequency in our PD patients was 4.5 ± 0.3 Hz (average ± SD). Tremor frequency in patients with PD is constant, usually between 4 and 6 Hz, and exceptionally up to 11 Hz /1/. Therefore the resonance frequency of type 1 and type 2 sensors did not interfere with tremor evaluation in PD patients. The typical upper frequency range of most tremors, with the exception of primary orthostatic tremor, is below 12 Hz; therefore, as far as sensor resonance is concerned, sensors in configuration 2 are appropriate for measurement of most types of hand tremor. Compared to tremor sensors in configuration 2, tremor sensors in configuration 1 gave a higher voltage output for a given angle of deflection. This was due to a relatively high degree of sensor bending in configuration 1, to adapt the sensor shape to a specific hand contour. Configuration 2 had two major advantages over configuration 1: (i) a smaller voltage output for a given angle of deflection enables measurement of large angles at the same voltage input settings (± 10 V) of an AD data acquisition board and (ii) hand tremor measurements were not impeded by variations in hand size. In patients with large or small hands it was difficult to ensure a good fit with sensors in configuration 1.

Hand tremor amplitude was evaluated by tremor sensors and clinically with the TRGRS. Both methods were in agreement (Figure 7) when assessing APO induced hand tremor changes; the observed and calculated TRGRS were in a perfect linear correlation. The presented hand tremor sensors can measure the changes in hand tremor amplitude over time. Figure 8 shows the changes in finger and wrist tremor amplitude after APO application during a 70 min time window.

Tremor assessment methods can measure clinically undetectable tremor /6,7,8,9/. The presented force transducer tremor evaluation method can also measure clinically undetectable tremor in PD patients. The absolute limit of the method's sensitivity is determined by the common noise amplitude which is one order of magnitude smaller than the smallest calibrated sensor output voltage amplitude.

Multidimensional evaluations are recommended for assessment of tremor severity in clinical trials /15/. Electromagnetic devices can track motion with six degrees of freedom (translational and rotational) /7,8/. The presented force transducer method measures joint movement with two degrees of freedom and provides an effective, simple and low cost alternative to multidimensional electromagnetic devices /6,7/ or 3D video tremor evaluation methods /8,9/ for hand tremor evaluation in PD patients.

The shape of a force transducer tremor sensor can be adapted to fit the contour of a specific joint (Figure 2,3). This modification does not degrade the sensor's sensitivity or dynamic range but does require recalibration (Figure 6).

5 Conclusions

We developed and tested a tremor evaluation method that measures hand tremor amplitude with reference to the joint involved in tremor movement. This method reduces between-subjects and within-subject variability of hand tremor measurements and also locates the hand muscle groups that are most active in tremor movement thus enabling their local treatment.

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Samo Ribarič
Institute of Pathophysiology, Faculty of Medicine,
Zaloška 4, SI-1000 Ljubljana, Slovenia
Tel.: +386 1 5437053, Fax.: +386 1 5437021,
E-mail: samo.ribaric@mf.uni-lj.si

Janez Rozman
ITIS d.o.o. Ljubljana, Center for Implantable Technology and Sensors, Lepi pot 11, SI-1001, Ljubljana, Slovenia

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