A New Myohaptic Device to Assess Wrist Function in the Lab and in the Clinic – The Wristalyzer

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Abstract. Wristalyzer is a portable robotic device combining haptic technology with electromyographic assessment. It allows to assess wrist motion in physiological and pathological conditions by applying loads and mechanical oscillations, taking into account the ergonomy and the angular positioning of the joints. The wristalyzer works in a free or loaded mode for assessment of metrics of motion and tremor, analyzes the behavior of the wrist joints and the associated muscle activities during delivery of mechanical oscillations, estimates the maximal voluntary contraction, assesses automatically the impedance of the wrist for assessment of rigidity or spasticity. Position, torques and electromyographic activities are analyzed in real time. The device characterizes the effects of damping on voluntary motion. A personal computer implements control loops and user application. This is the first standardized tool to assess wrist motion with high accuracy and reliability using the haptic technology with concomitant investigation of muscle activity.

Keywords: tremor, wrist, haptic, damping, oscillations.

1 Introduction

Researchers and clinicians dealing with assessment of joint properties, such as the wrist, face several difficulties [1]. From the clinical point of view, the estimation of wrist features during motion remains a challenge. Evaluating accuracy of voluntary motion, spasticity, rigidity or hypotonia is clinically difficult [2]. Although clinical scales have been proposed, they still depend on a subjective assessment by clinicians and intra-rater/inter-rater fluctuations are recognized as a source of problems for the quantification of neurological deficits, both for acute patients as well as for follow-up in chronic conditions affecting the brain, spinal cord or the peripheral nervous system [1, 3]. Although several tools have been proposed in various laboratories worldwide to study wrist function, they are not standardized and are rarely used by neurologists in their daily practice, the users being reluctant to use them because of complexity and time constraints. Neurological tremor is a typical example of difficulties encountered

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to extract features that could be transferred in other research centers or in the clinical practice for a better management of patients. Indeed, methodological differences between various laboratories have been an obstacle for the identification of robust measures that could be transferred to other laboratories [4]. Distinct experimental setups have hampered the identification of robust measures. In addition, sensitive measures often require normalization procedures which are specific for individual laboratories [4]. Moreover, important factors, such as comfort which has appeared to be a key-experimental parameter, have been underestimated or even totally ignored in the past. Haptic robots and brain-computer interfaces are being used more and more in medicine and virtual reality. Stroke and neurological injuries are examples of causes of disabilities for which robotic devices are used as tools for treating movement deficits [5,6,7]. For economic, social and medical reasons, there is a growing need to develop realistic force-feedback tools, including in the field of simulation for instance in surgery [8]. Haptic devices are used in rehabilitation with the aim to improve recovery of the patient more efficiently, to improve training procedures and also eventually to decrease costs related to medical care [9,10,11]. Recent studies support the use of haptic guidance or visual demonstration by robots to improve the teaching of movements [7].

We have designed and built a new tool to investigate and monitor sensitively the functions of the wrist, combining haptic technology and muscle analysis. The so-called myohaptic wristalyzer device has typical applications in acute and chronic neurological patients, but can be used also for rehabilitation or training purposes.

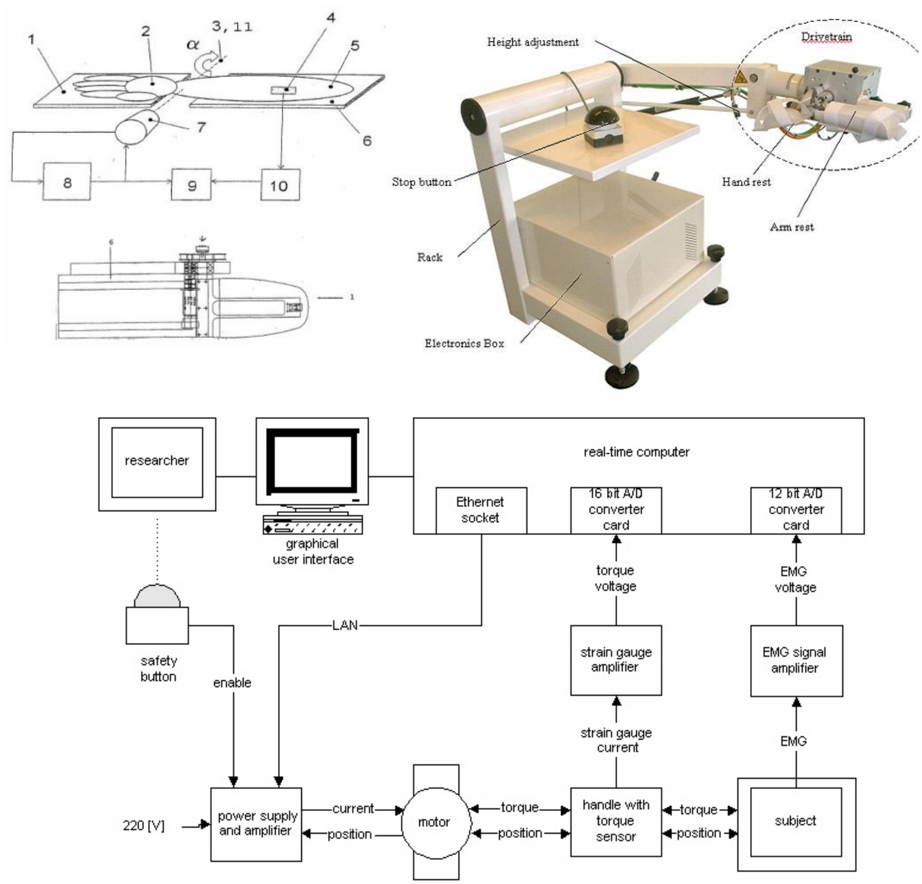
2 Description of Wristalyzer

The principle of the myohaptic device is illustrated in figure 1-left. The system block diagram is shown in figure 1-bottom. The wristalyzer (figure 1-upper right) is a mechatronic myohaptic system including: a rack with a stable base, a moving unit which can be adjusted for height and the left/right side, a controller which can be commanded from a host computer with a Ethernet card (100 Mbps), a signal acquisition unit with 4 channels for electromyographic (EMG) studies. The hand is fixed with velcro strips. End stops prevent excessive stress according to the biomechanical constraints in the patient investigated or the experimental conditions.

Mechanical characteristics. Angular accuracy is 0.35 deg, nominal torque is 6 Nm, maximal rotation velocity is 2000 degrees/sec, with a range of motion of -60 to +60 degrees in one degree of freedom.

EMG sensors. Commercially available EMG sensors can be connected to the analog inputs. Current configuration allows to assess 4 EMG channels, with a sampling rate of 2048 Hz per channel.

Power requirements. The input voltage range is from 230 VAC, frequency from 50-60 Hz. The power consumption does not exceed 1200W.



Component	Description
graphical user interface	IBM compatible PC running Microsoft Windows XP or Windows Vista
real-time computer	Advantech IPC-6606 industrial computer with ADLink 8111 A/D Card
power supply	Phoenix Contact, 24V 10A
motor	SMHA100
motor amplifier	Parker drive with proprietary MOOG FCS-net CPI board
handle with torque sensor	proprietary MOOG-FCS torque sensor 20 Nm Max (strain gauge)
strain gauge amplifier	proprietary MOOG-FCS strain gauge amplifier, 500x
EMG signal amplifier	Electrodes DE-2.1 Delsys EMG sensors

Fig. 1. Upper left: Principle of the wristalyzer. 1: moving unit; 2: hand; 3: rotation axis of the motor; 4: set of EMG electrodes; 5: proximal segment of the limb; 6: haptic device; 7: motor; 8: controller; 9: analog acquisition unit; 10: electrical signals; 11: rotation axis of the hand. **Upper right:** Illustration of the wristalyzer with its main components: rack with wheels, main unit, drivetrain. The mechatronic device includes a position encoder embedded in the motor casing and a torque sensor on the moving part attaching the hand flap (manipulandum) to the motor. **Bottom:** System block diagram of the wristalyzer.

Hardware/software. The system comprises a direct drive brushless motor with a high resolution encoder, and a dedicated 16-bit resolution strain gauge torque sensor integrated into the mechanical interface to the manipulandum. The haptic inner control loop runs an an embedded haptic server computer running a real time operating system on a 2048 Hz interrupt generated by a hardware clock. The haptic server functions and data can be accessed both by a dedicated API and by a web browser. The controlling user application runs on a separate Windows computer. It has a graphical user interface and a file logging capability.

Safety and ergonomic features. The system comprises a stop button. The user can press the button whenever required. This stops the motor immediately. Size and shape of the manipulandum are adapted to the upper limb configuration. The axis of the motor can be moved easily and quickly by the user in more than one plane, therefore manipulandum can be oriented in specific positions. During the evaluations subjects are comfortably seated.

3 Evaluation Procedures and Results

The reliability of mechanically-delivered oscillations has been investigated earlier using a first generation wristalyzer [12]. Comparison with a conventional accelerometer demonstrated a high accuracy in terms of reproducibility of frequency and amplitudes of oscillations. In this section we describe the analysis of maximal voluntary contraction, metrics of voluntary motion, tremor, effect of motion loading and of mechanically-imposed wrist oscillations. Analysis has been performed with subjects comfortably seating, with the right hand fixed in the manipulandum. Orientation and height of the drivetrain was adapted taking into account the ergonomy of each subjects. Subjects performed visually-guided tasks. Details concerning the subjects are provided in each subsection.

Free Motion – Assessment of Maximal Voluntary Contraction (MVC) and Metrics of Voluntary Motion. Figure 2-left shows the position, torque and the associated EMG activities in a right-handed healthy subject performing successive MVC with the right hand. Bursts of EMG activities are clearly identified during force generation. Figure 2-right-top illustrates a typical cerebellar hypermetria (overshoot of the target) of the right hand in a right-handed patient presenting a severe cerebellar atrophy and exhibiting clinically a marked axial and appendicular cerebellar syndrome with oculomotor ataxia, dysmetria of limbs, and gait ataxia. Hypermetria is a typical sign of cerebellar disease [13]. Figure 2-right-bottom shows the inverse linear relationship between movement times and maximal angular velocity in 4 control subjects asked to perform fast and accurate wrist flexions (aimed amplitude 0.1 rad). Movement times are markedly increased in the cerebellar patient. The linear relationship between movement time and maximal speed of motion is lost in case of cerebellar dysfunction.

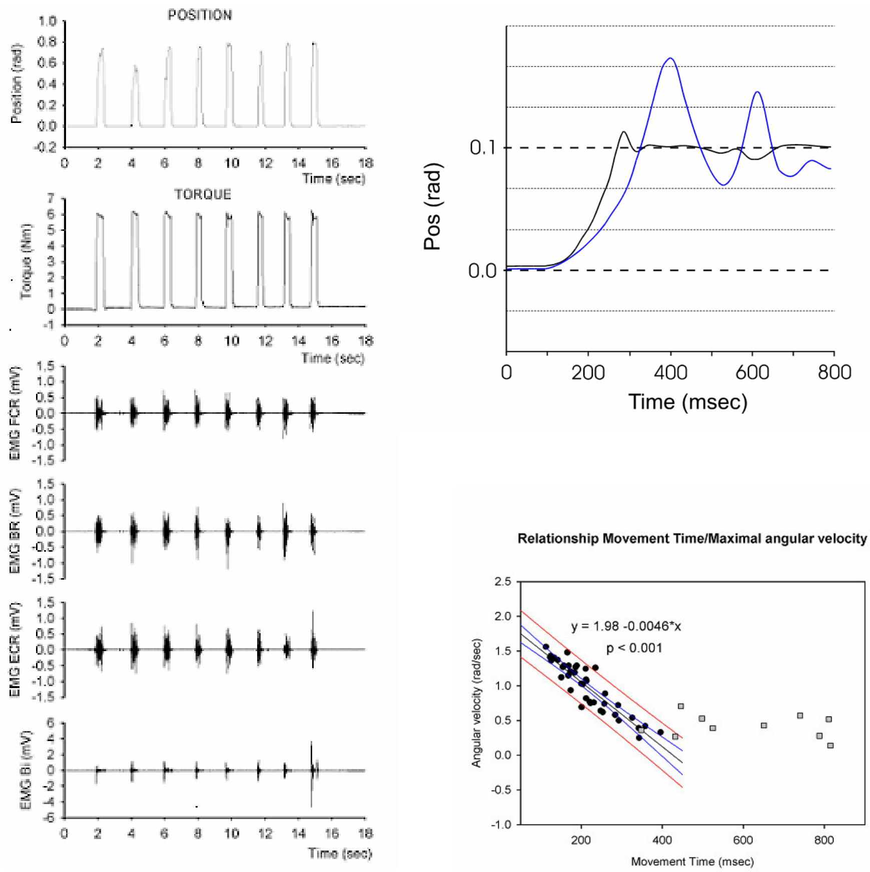


Fig. 2. Left: Recording of successive maximal voluntary contractions (MVC) in a control subject (age: 40 years). From top to bottom: position torque, and the associated EMG activities (respectively for the flexor carpi radialis FCR, the brachioradialis BR, the extensor carpi radialis ECR and the biceps brachii BI). Recording on the right side with surface EMG electrodes affixed on the skin. **Upper right:** Overshoot in a cerebellar patient (hypermetria; blue line). The hypermetric movement is followed by attempts to reach the aimed target. Normometria in a control subject (black line). Aimed target: 0.1 rad. **Bottom right:** Relationship between movement time and maximal angular velocity in a visually-guided reaching task (fast wrist flexion). Inverse linear relationship in controls (black dots). Blue: 95 % confidence bands; red: 95 % prediction bands. The movement times are increased markedly in a cerebellar patient (grey squares).

Tremor. Figure 3-left illustrates the action tremor recording in a patient presenting Parkinson’s disease, with asymmetrical deficits predominating on the right side. Angular motion, torques and corresponding EMG activities in the extensor carpi radialis muscle are illustrated. Power spectrum of position, torque and EMG trace identify a clear peak at 4.37 Hz.

Motion loading. Figure 3-right illustrates the beneficial effect of motion loading (damping) in a cerebellar patient asked to perform repetitive movements between two targets. The inability to perform alternate movements (a deficit called adiadochokinesia; [14]) is markedly reduced by damping.

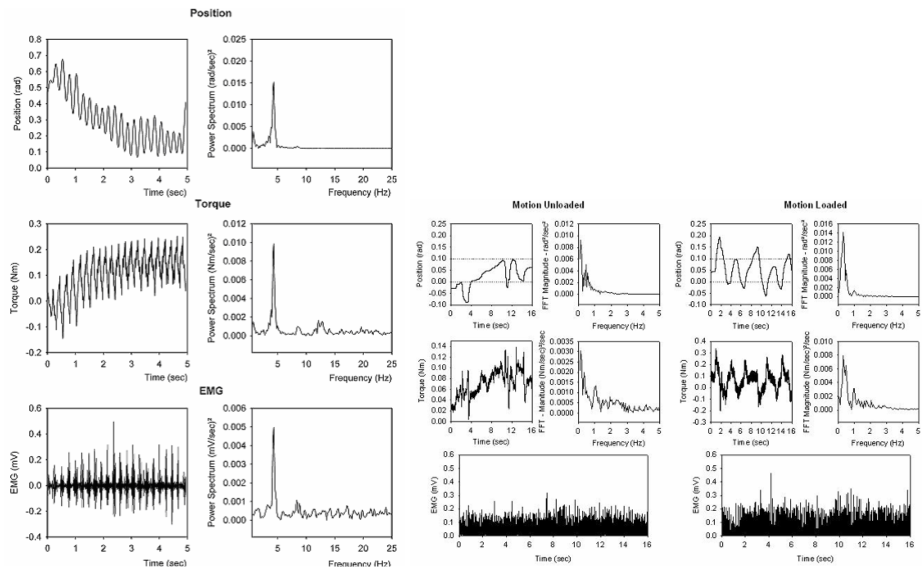


Fig. 3. Left: Action tremor in a patient presenting Parkinson's disease. Top panels: position and corresponding power spectrum. The tremor is well discernible. Middle panels: simultaneous torques and corresponding power spectrum. Bottom panels: EMG activities of the extensor carpi radialis (right side) and corresponding power spectrum. A peak frequency of 4.37 Hz is well visible in each power spectrum. **Right:** Effects of loading on alternate movements between 2 targets in a cerebellar patient. The patient is asked to perform alternate movements between 2 targets located at 0 and 0.1 rad. On the left, motion is unloaded. Motion is loaded on the right. Note the marked difficulty to perform alternate movements between 2 targets in the basal condition and the marked improvement with loading. Bottom panels: rectified EMG activities in the extensor carpi radialis.

Effects of mechanically-imposed wrist oscillations. Figure 4-left illustrates the effects of mechanically-imposed high-frequency oscillations (30 Hz) on muscle responses. A rhythmic response is visible on the EMG trace. The wristalyzer can also assess the EMG activities in response to stretches. The stretch responses are abnormal in a neurological patient exhibiting a severe paraneoplastic syndrome (frequency of imposed oscillations: 15 Hz; figure 4-right). Time-frequency analysis shows diffuse peaks, unlike in the control subject (figure 5-left). The sonogram method confirms the pathological response in the patient (figure 5-right; IgorPro 6, Wavemetrics, USA).

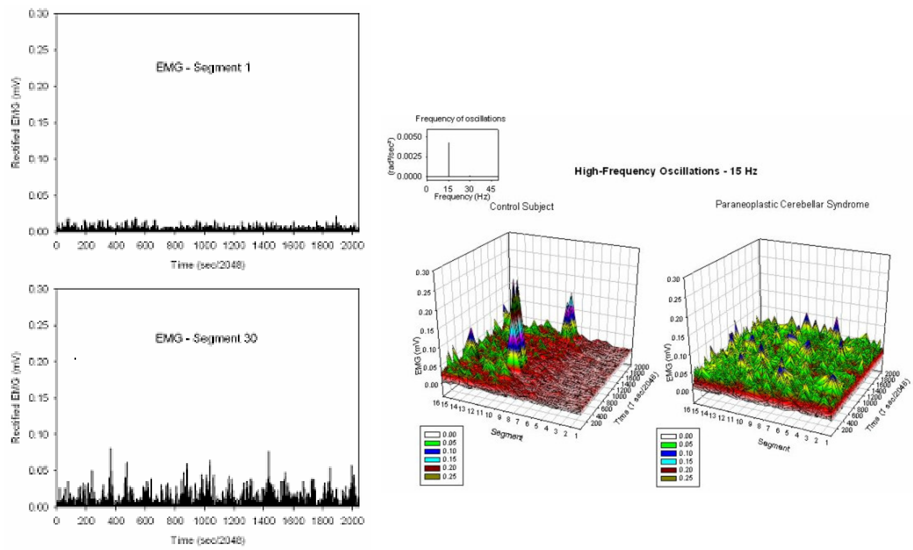


Fig. 4. Left: Rectified EMG responses during 30 Hz oscillations in a control subject. Recordings in the extensor carpi radialis muscle. **Right:** Abnormal EMG responses to 15 Hz oscillations (amplitude of oscillations: 0.1 rad) in a neurological patient exhibiting dysmetria and kinetic tremor (right panel). The plot illustrates the rectified EMG traces in the extensor carpi radialis muscle. Left panel: control subject.

4 Discussion

This myohaptic device has several advantages: portability with a dedicated rack, possibility to move the axis of the rotation of the motor, ergonomy of the manipulandum, comfort of recording, automatic assessment in a laboratory or at the bedside of a patient, capacity to deliver very high frequency of oscillations which are very accurate thanks to the use of the haptic controller with standardized procedure, from a research point of view the wristalyzer allows a better understanding of the mechanisms of neurological deficits such as tremor or dysmetria. Tremor is composed of mechanical-reflex and central-neurogenic components, which are superimposed on a background of fluctuations in muscle force [15]. Modifications in the amplitudes of specific frequency bands of tremor are indicative of the central and peripheral modulation of tremor [16]. We have shown in a group of patients presenting a postural tremor that high-frequency oscillations (13.3 Hz) applied on one limb modify the variability of tremor (assessed by variability of PSD peaks) contralaterally, unlike in control subjects [12]. We also found that the generator underlying orthostatic tremor, a tremor presumed to be of pure central origin, is very sensitive to mechanical perturbations. The abnormal excitability of the sensorimotor cortex associated with postural tremor is likely to render patients more susceptible to afferent volleys [17,18]. The inter-hemispheric coupling via the corpus callosum is a very good anatomical candidate to explain this inter-limb transfer effect. Another possibility is the cerebellar coupling between both hemispheres [19]. The fact that previous attempts, such as

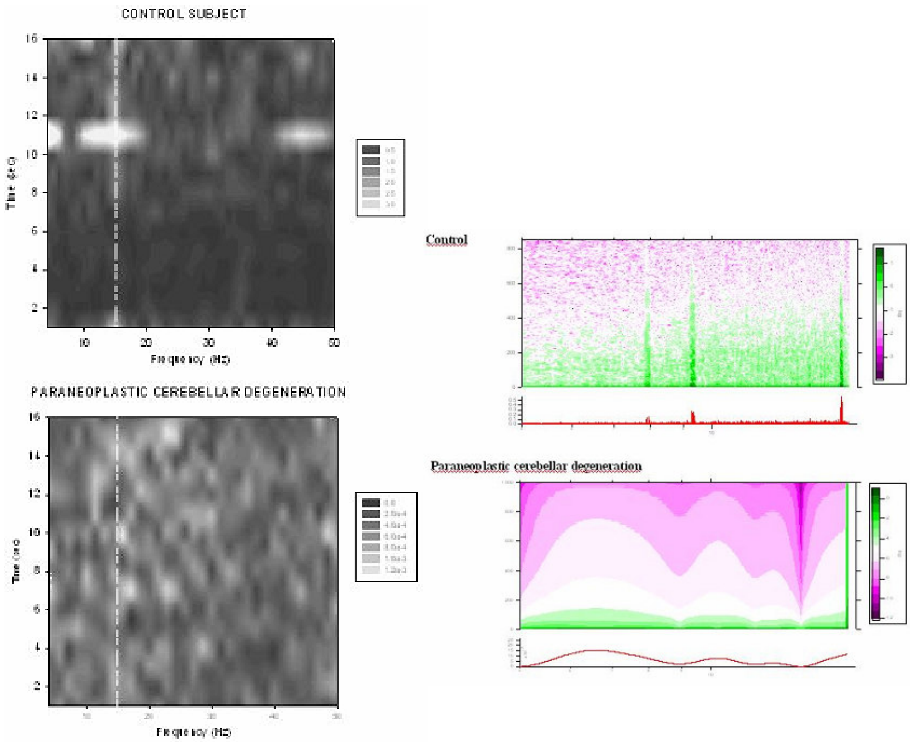


Fig. 5. Left: Time-frequency analysis confirms the distorted muscle responses in the cerebellar patient as compared to the healthy subject. **Right:** Sonogram of rectified EMG responses in the control subject (top panel) and the neurological patient (bottom panel).

with electrical stimuli delivered over tendons, failed to show a resetting effect (pseudo-insensitivity) can be explained by the inability of an electric shock to mimick sufficiently the afferent volleys which occur during joint motion [12]. Another potential application is the sensory processing itself. A distorted processing of sensory informations emerging from stretch receptors has been proposed recently in Multiple Sclerosis [18]. In Essential Tremor, an abnormal illusion of movement induced by vibration was found recently [20]. Data were consistent with excessive stiffness of muscle spindle dynamic nuclear bag 1 fibres. A reduced response of the –relatively- inelastic muscle spindle to dynamic stimuli generates a delayed and prolonged activation of Ia afferent fibres during the stretching of muscle fibres. The structures of the central nervous system involved in sensorimotor processing may attempt to compensate by adjusting the timing of the feedback loop to reduce oscillations.

Another factor underlying tremor is motor unit synchronization. This is enhanced in neurological disorders, leading to an increase in the magnitudes of oscillations [21]. This may be caused by a simultaneous increase in muscle spindle afferent activity from the tremulous muscle, reflecting a near maximal supraspinal and segmental common synaptic input onto motoneurons. The beneficial effect of beta-adrenoreceptor blockers, which act via the beta 2-adrenoreceptors in muscle spindles, is consistent with the idea of pathological activity emerging from the muscle [22]. In Parkinson's disease, a lack of inhibition renders motoneurons particularly susceptible to oscillations. Several arguments point towards an abnormal transcortical reflex in distal upper limb in Parkinson's disease [23,24]. The study of the relationship between angular changes and related torques in response to sudden stretch perturbations shows distorsions in the dynamic profiles [25]. The wristalyzer allows the estimation easily and with high accuracy. The demonstration of abnormal responses to high-frequency stretches in a cerebellar patient fits with the hypothesis of a role of the cerebellar pathways in the modulation of magnitude and timing of muscles activities.

5 Conclusion

In conclusion, we have presented here a new robotic device to characterize with high accuracy and in a standardized way motion of the wrist. The wristalyzer can be used for research or clinical purposes. Typical examples for research could be to investigate strategies aiming to maximize retention of motor tasks, to assess the effects of somatosensory stimulation on cortical plasticity and recovery, or to investigate the motor unit recruitment during isotonic tasks.

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References

1. Cicchetti, D., Bronen, R., Spencer, S., Haut, S., Berg, A., Oliver, P., Tyrer, P.: Rating scales, scales of measurement, issues of reliability: resolving some critical issues for clinicians and researchers. J. Nerv. Ment. Dis. 194(8), 557–564 (2006)
2. Johnson, G.R.: Outcome measures of spasticity. Eur. J. Neurol (suppl. 1), 10–16 (2002)
3. Woolacott, A.J., Burne, J.A.: The tonic stretch reflex and spastic hypertonia after spinal cord injury. Exp. Brain Res. 174(2), 386–396 (2006)
4. Raethjen, J., Lauk, M., Köster, B., Fietzek, U., Friege, L., Timmer, J., Lücking, C.H., Deuschl, G.: Tremor analysis in two normal cohorts. Clin Neurophysiol 115, 2151–2156 (2004)
5. Reinkensmeyer, D.J., Emken, J.L., Cramer, S.C.: Robotics, motor learning and neurologic recovery. Annu. Rev. Biomed Eng. 6, 497–525 (2004)
6. Hesse, S., Schmidt, H., Werner, C., Berdeleben, A.: Upper and lower extremity robotic devices for rehabilitation and for studying motor control. Curr. Opin. Neurol. 16, 705–710 (2003)
7. Liu, J., Cramer, S.C., Reinkensmeyer, D.J.: Learning to perform a new movement with robotic assistance: comparison of haptic guidance and visual demonstration. J. NeuroEng. Rehab. 3, 2 (2006)
8. Lemole Jr., G.M., Banerjee, P.P., Luciano, C., Neckrysh, S., Charbel, F.T.: Virtual reality in neurosurgical education: part-task ventriculostomy simulation with dynamic visual and haptic feedback. Neurosurgery 61(1), 142–148 (2007)

9. Lambercy, O., Dovat, L., Gassert, R., Burdet, E., Teo, C.L., Milner, T.: A haptic knob for rehabilitation of hand function. IEEE Trans. Neural Syst. Rehabil Eng. 15(3), 356–366 (2007)
10. Broeren, J., Rydmark, M., Björkdahl, A., Sunnerhagen, K.S.: Assessment and training in a 3-dimensional virtual environment with haptics: a report on 5 cases of motor rehabilitation in the chronic stage after stroke. Neurorehabil Neural Repair 21(2), 180–189 (2007)
11. Mali, U., Goljar, N., Munih, M.: Application of haptic interface for finger exercise. IEEE Trans. Neural Syst. Rehabil Eng. 14(3), 352–360 (2006)
12. Grimaldi, G., Lammertse, P., Manto, M.: Effects of wrist oscillations on contralateral neurological postural tremor using a new myohaptic device (wristalyzer). In: Proceedings of the 4th IEEE-EMBS, Cambridge, UK, pp. 44–48 (2007)
13. Manto, M.: Cerebellar ataxias. In: Hallett, M. (ed.) Movement Disorders. Handbook of Clinical Neurophysiology, pp. 491–520. Elsevier, Amsterdam (2003)
14. Beppu, H., Suda, M., Tanaka, R.: Analysis of cerebellar motor disorders by visually guided elbow tracking movement. Brain 107, 787–809 (1984)
15. Elble, R.J.: Characteristics of physiological tremor in young and elderly adults. Clin Neurophysiol 114, 624–635 (2003)
16. Stiles, R.N.: Mechanical and neural feedback factors in postural hand tremor of normal subjects. J. Neurophysiol. 44, 40–59 (1980)
17. Pinto, A.D., Lang, A.E., Chen, R.: The cerebellothalamocortical pathway in essential tremor. Neurology 60, 1985–1987 (2003)
18. Feys, P., Helsen, W.F., Verschueren, S., Swinnen, S.P., Klok, I., Lavrysen, A., Nuttin, B., Ketelaer, P., Liu, X.: Online movement control in multiple sclerosis patients with tremor: effects of tendon vibration. Mov. Disord. 21, 1148–1153 (2006)
19. Manto, M., Nowak, D.A., Schutter, D.J.: Coupling between cerebellar hemispheres and sensory processing. Cerebellum 5(3), 187–188 (2006)
20. Frima, N., Grunewald, R.A.: Abnormal vibration induced illusion of movement in essential tremor: evidence for abnormal muscle spindle afferent function. J. Neurol Neurosurg Psychiathy 76, 55–57 (2005)
21. Logigian, E.L., Wierzbicka, M.M., Bruyninckx, F., Wiegner, A.W., Shahahi, B.T., Young, R.R.: Motor unit synchronization in physiologic, enhanced physiologic and voluntary tremor in man. Ann Neurol. 23(3), 242–250 (1988)
22. Abila, B., Wilson, J.F., Marshall, R.W., Richens, A.: The tremorolytic action of beta-adrenoreceptor blockers in essential, physiological and isoprenaline-induced tremor is mediated by beta-adrenoreceptors located in deep peripheral compartment. Br. J. Clin Pharmacol. 20, 369–376 (1985)
23. Day, B.L., Riescher, H., Struppler, A., Rothwell, J.C., Marsden, C.D.: Changes in the response to magnetic and electrical stimulation of the motor cortex following muscle stretch in man. J. Physiol. 433, 41–57 (1991)
24. Palmer, E., Ashby, P.: Evidence that a long latency stretch reflex in humans is transcortical. J. Physiol. 449, 429–440 (1992)
25. Sinkjaer, T., Hayashi, R.: Regulation of wrist stiffness by the stretch reflex. J. Biomech. 22, 1133–1140 (1989)