ASSESSMENT OF GRIP FORCE CONTROL IN PATIENTS WITH MUSCULAR DYSTROPHY

OCENJEVANJE KOORDINACIJE SILE PRIJEMA PRI BOLNIKIH Z MIŠIČNO DISTROFIJO

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Abstract – Background. *The majority of hand functionality tests are based on qualitative assessment which largely depends on the experience of the therapist. Computer-assisted methods can provide more objective and accurate measurements of the grip force and other parameters related to grasping.*

Methods. *We analysed the grip force control in 12 patients with muscular dystrophy using the tracking system developed. The system consists of a grip-measuring device with end-objects assessing the force applied in different grips. The device was used as input to a tracking task where the patient applied the grip force according to the visual feedback from the computer screen. Each patient performed two tasks which consisted of tracking a ramp and sinus target.*

Results. *We analysed the maximal grip force as assessed in the ramp task and the tracking accuracy of the sinus task. The results are compared among five different grips (cylindrical, lateral, palmar, pinch and spherical grip), applied with dominant and non-dominant hand. The results show no significant difference in tracking accuracy between the dominant and non-dominant hand.*

Conclusions. *The results obtained in tracking the ramp target showed that the method could be used for the assessment of the muscle fatigue, providing quantitative information on muscle capacity. The results of the sinus-tracking task showed that the method can evaluate the grip force control in different types of grips, providing information on hand dexterity, muscle activation patterns or tremor.*

Ključne besede: *prijemanje; sila prijema; funkcionalnost roke; mišična distrofija; sledenje*

Izvleček – Izhodišča. *Poglavitna slabost obstoječih metod za ocenjevanje funkcionalnosti roke v ožjem smislu je predvsem v subjektivnosti ocenjevanja, ki je v veliki meri odvisno od izkušenosti terapevta. Z računalniškimi meritvami je mogoče povečati objektivnost in natančnost postopkov merjenja sile prijema ter ocenjevanja funkcionalnosti roke.*

Metode. *V raziskavi smo z računalniškim merilnim sistemom analizirali koordinacijo sile prijema pri 12 bolnikih z mišično distrofijo. Merilni sistem vključuje računalnik ter merilnik sile prijema, kjer je z različnimi nastavki mogoče natančno izmeriti silo pri različnih prijemih. Merilnik je bil vključen v nalogo sledenja sile prijema, kjer je pacient s prilagajanjem sile prijema sledil različnim tarčam na zaslonu. Ocenjevali smo sledenje sile pri dveh različnih nalogah: sledenje linearno naraščajočega signala in sinusnega signala z uporabo petih različnih prijemov (cilindrični, lateralni, pincetni, uščipni ter sferični prijem).*

Rezultati. *Pri sledenju linearnega signala smo ocenjevali maksimalno silo, ki jo je bolnik dosegel pri posameznih prijemih. Iz rezultatov smo analizirali tudi utrujanje mišic pri izvajanju naloge. Pri sledenju sinusnega signala smo ocenjevali natančnost koordinacije sile prijema, ki je povezana s senzomotoričnim sistemom funkcije prijemanja. V članku so prikazani rezultati sledenja sile pri petih prijemih ter primerjava med dominantno in nedominantno roko. Pri večini bolnikov je bila natančnost največja pri cilindričnem in lateralnem prijemu. Rezultati niso pokazali razlik v natančnosti glede na dominantnost roke.*

Zaključki. *S predstavljenim merilnikom sile je mogoče natančno meriti silo pri različnih prijemih. Rezultati so pokazali, da je opisani merilni sistem mogoče uporabiti za ocenjevanje natančnosti koordinacije sile prijema pri bolnikih z mišično distrofijo, ugotavljanje prisotnosti tremorja ter ocenjevanje utrujanja posameznih mišic.*

Introduction

Grasping is one of the most important and complex human activities. The functionality of the hand can be promoted by using different objects or tools for the interaction with the environment. The key goal of grasping is a stable grasp of the object where the fingers have to apply forces that satisfy constraints of the object and the task (1). The accomplishment of the task depends on the selection of suitable hand posture and accurate grip force control where different muscles of the hand are activated in synergy to produce appropriate pressure on the object surface (2). Accurate grip force control is essential in performing daily activities such as grasping of fragile objects, resistance to external forces (e. g. holding a spoon) and applying movement to the object (e. g. turning a knob, opening a jar) (2).

The functionality of the hand depends on the motion range of the fingers and wrist, grip strength and dexterity (3). Central nervous system injury, hand injury or muscular weakness can greatly reduce the ability to grasp and manipulate objects in daily activities. In rehabilitation and therapy, different tests are used to assess patient's muscle strength and hand mobility (3, 4). The assessment of individual muscles activity (e. g. EMG) and joint motion range can provide only a partial information on patient's hand functionality because of difficult muscle isolation during the assessment, the influence of patient's motivation and other physiological and biomechanical factors affecting the clinical assessment (3–6). The grip-strength testing is mainly focused on the measurement of the maximal voluntary grip force that provides information on short-duration muscle strength (7). The grip strength is usually assessed using different mechanical dynamometers that measure the level of the applied grip force providing no information on the direction and dynamics of the force. The dynamometers used are often not suitable for accurate measurements of low-level forces because their measurement range is too large in respect to the force applied (7). Possibility of detection of small changes in grip strength following therapy or progression of disease is therefore limited. In daily living 90% of activities can be accomplished by the grip forces under 40 N (8) and in this context the maximal voluntary grip force reflects only a partial information on the hand functionality (3). The functionality of the hand depends on the functional force that can be applied while manipulating the object. In precision grips the requirement is mainly on the accuracy of the applied force, while in power grips the level of the force is more important (1).

A drawback of the existing tests originates mainly from the subjectivity of the assessment which largely depends on the experience of the therapist. An objective hand functionality assessment is important in evaluation of the progress of the therapy. Computer assisted methods can increase the accuracy and objectivity of the assessment by providing quantitative measurements on sensory-motor functions of the hand which affect the grip force control and dexterity. In this paper we propose a grip-force tracking system for the assessment of sensory-motor functions related to grasping. Tracking can be defined as a controlled movement or force application with visual feedback on the performance of the task (9). Tracking tasks have been used previously to assess the development of human sensory-motor functions (10), coordination of grip force in Parkinson's disease (11), to train hemiplegic patients (12) and to assess grip force control in healthy persons (13). Most of the previous studies focused only on one type of grip. We believe that it is essential to evaluate different grips used in performing daily activities to obtain an objective information on hand functionality.

Instrumented objects have been proposed previously (14–16) to assess the grip forces acting on objects which are in shape and size similar to the objects used in daily living. Such instruments allow real-time measurement of the grip force while performing different tasks. We have built a grip-measuring device with end-objects of different shapes to assess the forces in different types of grips. The selection and size of the end-objects was based on the upper extremity part of the Fugl-Meyer evaluation method (4). The grip-measuring device allows real-time measurement of the grip force providing information on direction and dynamics of the applied force (17). The device was used as input to a tracking task, where a person applied the grip force according to the visual information from the computer screen. The proposed tracking system was used to evaluate grip force control in 12 patients with muscular dystrophy (MD). We studied the grip force control in five different grips: cylindrical, lateral, palmar, pinch and spherical grip.

Methods

A. Grip-Measuring Device

We designed a grip-measuring device (Figure 1) to assess the grip forces in different type of grips. The instrument is based on the force transducer JR3 (JR3, Inc., Woodland, USA) capable of measuring three-dimensional forces, providing information on the grip strength and direction of the applied force. The sensor is attached to a metal construction allowing the transfer of forces from the end-object to the sensory unit. The grip-measuring device can be fitted with different end-objects which have the shape of objects used in daily living, such as a pencil, thin plate, ball and cylinder. Each measuring object is divided along the longitudinal axis into two symmetrical parts that shape into the full object when attached to the device. The selection and size of the objects was based on the upper extremity part of the Fugl-Meyer hand evaluation method (4). When the person grasps the end-object, the force sensor measures the grip force on the object. The grip-measuring device was calibrated to measure forces up to 100 N (equivalent mass of 10 kg). The resolution of the measured force is 0.01 N (0.001 kg) in the measuring range of 0–25 N (0–2.5 kg), 0.03 N (0.003 kg) in the range of 25–50 N (2.5–5 kg) and about 0.05 N (0.005 kg) in the range of 50–100 N (5–10 kg). The device was connected to a personal computer with a data acquisition card where the grip force data were sampled with a frequency of 100 Hz.

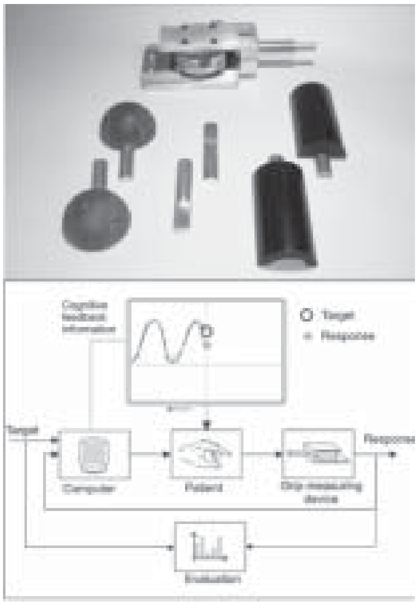

Figure 1. *The grip-measuring device with different end-objects used for the measurement of grip forces (above). The block scheme of the grip-force tracking system for the hand functionality assessment (below). The patient applies the grip force to the grip-measuring device according to the visual feedback from the computer screen.*

B. Tracking Task

The goal of the tracking task was to apply the grip force on the grip-measuring device according to the visual information from the computer screen (Figure 1 below). The person was presented with a target signal indicated in blue colour and the measured grip force response indicated in red colour. A blue ring located in the centre of the screen moved vertically according to the target signal, leaving a blue trail that moved from the centre of the screen to the left representing the time history of the signal. The measured response was presented with a red spot whose vertical position corresponded to the grip force applied perpendicularly to the end-object surface of the grip-measuring device. The patient's task was to bring the red spot inside of the blue ring and to track the position of the ring by applying the appropriate grip force to the grip-measuring device. The tracking task was programmed in Matlab-Simulink (The MathWorks, Inc., Natick, USA). The complexity of the tracking task could be adjusted by selecting the shape of the target signal (e. g. ramp, sinus, rectangular shape), setting the level of the required grip force and changing dynamic parameters of the target (e. g. frequency, speed). Selecting the appropriate task allows the assessment of the grip force control and dexterity in different grips, quantification of muscle fatigue, detection of tremor and assessment of reaction time (9).

C. Experiments

We analysed the grip force control in 12 right-handed patients (P1–P12; 3 female, 9 male patients) with muscular dystrophy. We assessed the tracking performance in five different grips: pinch, palmar, lateral, spherical and cylindrical grip, evaluating the dominant and non-dominant hand. Two different tracking tasks were selected for the experiment. The first task consisted of tracking a ramp target that increased in 15s from the initial value of 0N to the final value of 30N for the pinch and palmar grip, 60N for lateral and 70N for spherical and cylindrical grips. The patient was instructed to follow the target as long as possible and if unable to exert higher force, to keep the grip until the end of the trial which lasted 32 seconds. The second task consisted of tracking a sinus target with frequency of 0.1Hz. The amplitude of the signal was set at about 30% of the patient's maximal grip force as assessed in the ramp trial. The patient was asked to follow the moving target as accurately as possible by applying an appropriate force on the grip-measuring device. Each trial lasted 32 seconds.

During the test the patient was sitting in a wheelchair in front of the computer screen, with the forearm resting on a hand-support. For the maximal performance of the grip the elbow was positioned in a 90° flexion and the shoulder was in a neutral position (6). The grip-measuring device was located in the proximity of the patient's hand to allow a neutral wrist position. If a patient was unable to perform the grip within the required hand and arm position due to muscle contractures, the position and orientation of the grip-measuring device were adjusted to find the most adequate posture. The patients were required to maintain consistent grip during the assessment and were not allowed to use 'trick' movements. During the test the patient's hand posture was monitored by a therapist. The patients performed several test trials to get familiar with the task and the measuring procedure. Most of the patients required about 3–5 test trials of each task. The patients then performed two trials of each tracking task with 30–45 s of rest in between. The better result of the two trials was considered in further analysis.

D. Analysis

The performance of the ramp task was quantified by the average maximal grip force sustained for the duration of 5s at the point where the target first reached its maximal value (time interval 17–22 s) (Figure 2). The assessed grip force was used also for the selection of the amplitude for the sinus task where the amplitude was set at about 30% of the maximal force as obtained in the ramp task.

We assessed the performance of the sinus tracking by calculating the relative root mean square error (*rrmse*) between the sinus target Y_T and the measured output force Y_O (9):

$$rrmse = \sqrt{\frac{1}{T}\sum_{t=0}^{T}\frac{(Y_O(t)-Y_T(t))^2}{\max(Y_T)^2}}$$

The error was calculated over a time period T (30 s interval), where the initial two seconds of the trial, used for the adjustment of the grip, were excluded from the analysis. The relative tracking error describes the accuracy of the tracking which depends on the control of the muscles used in the particular grip. The error is normalised by the maximal value of the target signal to allow an objective comparison between the results obtained in different grips and patients.

Results

The results of the ramp test reflect the patient's grip force control when gradually increasing the grip force. The ramp test can be also used to assess the muscle fatigue while using different grips. Figure 2 shows the tracking results of the ramp test as performed by two patients (P9 and P12) who showed similar results in the maximal grip force value while using the cylindrical and palmar grip. The maximal grip force of the patient P9 in the cylindrical grip was about 65N. The patient

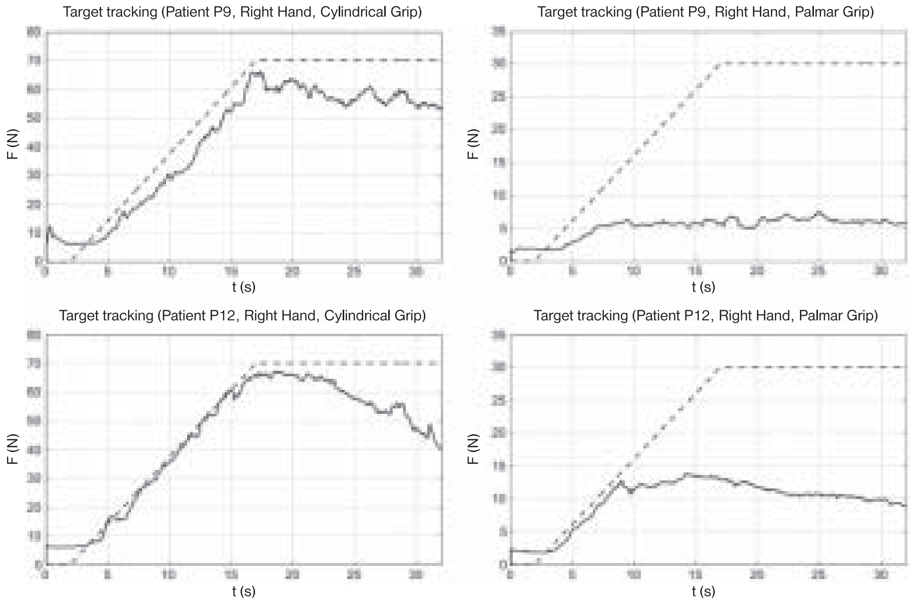

Figure 2. *The results of the ramp tracking as assessed in the patients P9 and P12 using cylindrical and palmar grip. The results show that both patients were able to exert the required grip force level in cylindrical grip but their force decreased because of muscle fatigue. Both patients produced much lower force in palmar grip.*

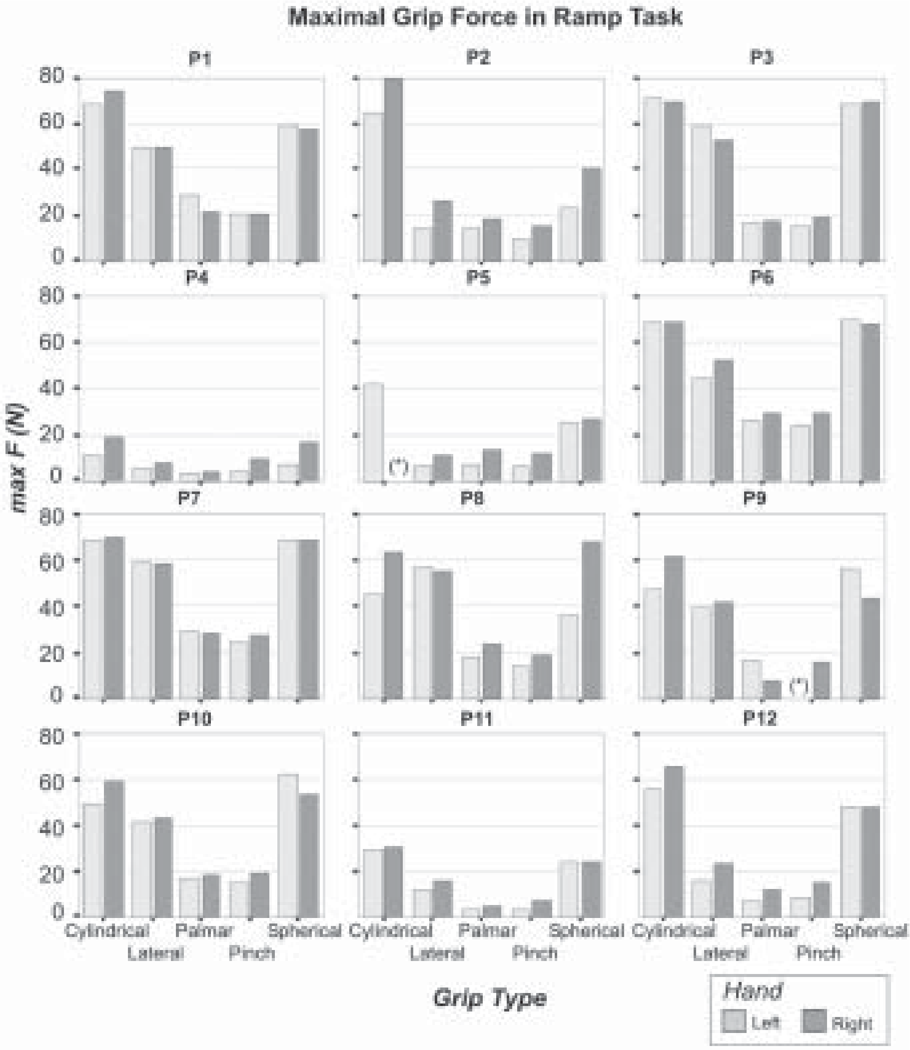

Figure 3. *The maximal grip forces of the 12 patients with muscular dystrophy as assessed in the ramp task compared within different grips. (* Patient was not able to perform the indicated grip.)*

was not able to retain the same force level until the end of the trial. The decrease of the grip force was about 18% in 15s. The patient P12 tracked the target more accurately and reached a similar force level but the decrease of the grip force was about twice as large (40% in 15 s) compared to the first patient. The results of the palmar grip (Figure 2) show that both patients lacked the required muscle force to reach the final target value. The patient P9 reached about 20% of the required force level and the patient P12 about 45%. The grip force of the patient P12 decreased for about 30% of the exerted force at the end of the trial.

In our experiment the ramp test was used to obtain the maximal grip force values for the individual patients, which were later used for setting the required peak target level of the sinus task. Figure 3 shows the results of the maximal grip force as assessed in 12 MD patients who performed the tracking task using five different grips (cylindrical, lateral, palmar, pinch and spherical grip). The patients P4, P5 and P11 were not able to exert higher-level grip forces in any of the grips tested. Only the patients P1, P3, P6 and P7 were in position to perform the task within the required grip force levels. The rest of the patients completed the task with average results. The results of the grip forces of the individual patient can be used to assess the fatigue of the muscles (18) used in the observed grips.

Figure 4 shows the results of the sinus task as assessed in the same two patients (P9 and P12) using the cylindrical and palmar grip. The patient P9 performed the task with less accuracy compared to the patient P12, where larger relative tracking error can be observed. The error increased in both patients when performing the task with the palmar grip. The results of the patient P9 show that the grip force trajectory is not smooth which reflects more abrupt muscle activation pattern that unables the patient to gradually increase or decrease the force.

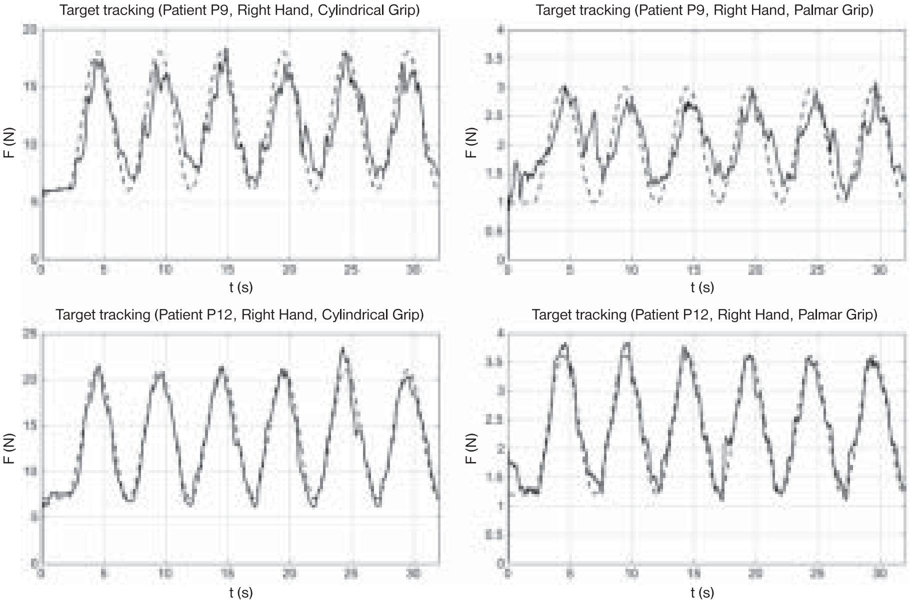

Figure 4. *The results of the sinus tracking as assessed in the patients P9 and P12 using cylindrical and palmar grip. The tracking results of the first patient show more abrupt muscle activation pattern that unables the patient to gradually increase or decrease the grip force. Both patients produced larger tracking error in palmar grip as compared to the cylindrical grip.*

The relative tracking errors assessed and compared among the patients are presented in Figure 5. The results are shown for different grips while performing the task with the dominant and non-dominant hand. The patients P1, P3, P5, P6, P8 and P12 produced lower tracking errors in all grips with respect to the other patients. The lower tracking error suggests a better grip force control resulting in greater hand functionality. We can conclude that the patients who could perform the task more accurately while applying different grips have more enhanced muscle control. Analysis of the results within patients showed that the largest tracking errors were produced in pinch and palmar grip while the errors in the cylindrical, lateral and spherical grips were smaller. There was no significant difference found between the dominant and non-dominant hand (one-way ANOVA, p=0.326), except for the patients P7 and P10 who produced lower tracking errors with non-dominant hand.

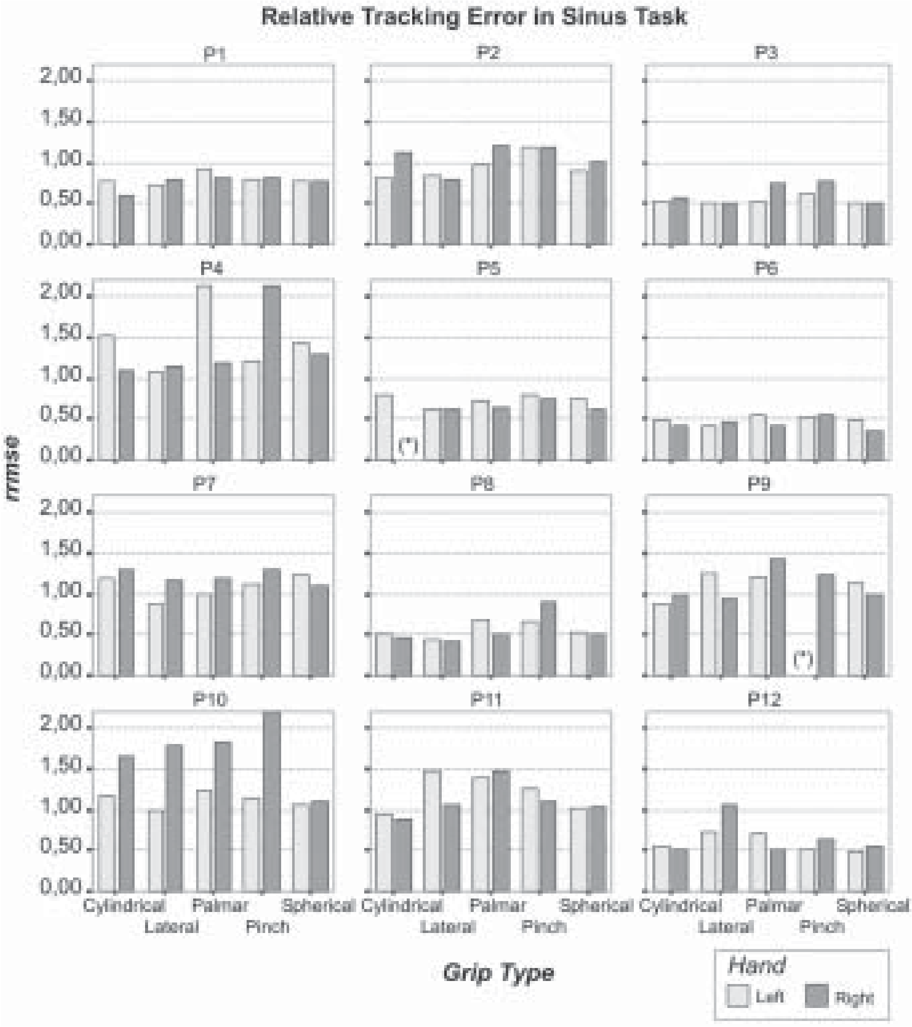

Figure 5. *Relative tracking error of the 12 patients with muscular dystrophy as assessed in the sinus task. The accuracy of the tracking depends on the control of the muscles used in the particular grip. (* Patient was not able to perform the indicated grip.)*

Conclusions

The purpose of this paper was to present the method for the evaluation of the grip force control in patients with muscular dystrophy. The use of computer assisted methods for hand functionality assessment can increase the objectivity of the evaluation. The grip-measuring device developed can be used for the assessment of the functional force applied while grasping objects similar to objects used in daily living. The device can measure the grip force with much greater accuracy as compared to the mechanical dynamometers, which are commonly used in rehabilitation environment. The high accuracy of the measurement allows detection of small changes in grip strength following therapy or progression of disease. The grip force can be measured in real-time providing the information on the direction and level of the applied force while assessing functional grips used in daily activities.

The results obtained in tracking of the ramp target showed that the method can be used for the assessment of the muscle fatigue, providing quantitative information on the muscle fatigue while performing grips used in daily activities. Accurate and objective evaluation of the muscle fatigue is needed when evaluating the progress of disease or the effect of therapy on the patient (18). The results of the sinus-tracking task showed that the method can evaluate the grip force control in different types of grips, providing information on hand dexterity, muscle activation patterns or to detect tremor. The results obtained in the patients with muscular dystrophy showed that most patients produced larger tracking errors in palmar or pinch grip compared to the other grips. Their tracking accuracy improved in cylindrical and lateral grip. The patients with higher hand functionality showed less significant differences between the grips tested.

The majority of the patients participating in this investigation expressed positive opinion about the grip-force tracking system. We believe that the cognitive feedback delivered to the patients could have also a positive therapeutical value. The tracking system can be applied as a training assistive device where the difficulty of the tasks would be increased throughout the therapy promoting in this way patient's hand mobility and grip force control. A similar grip-force tracking system with a low-cost force sensor could be developed on the basis of the results obtained and used at rehabilitation institutions for the evaluation of grasping and grip force control.

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References

1. Napier JR. The prehensile movements of the human hand. J Bone Joint Surg 1956: 38B; 902–13.
2. MacKenzie CL, Iberall T. Advances in psychology, 104: The grasping hand. Amsterdam: Elsevier Science B.V., 1994.
3. McPhee S. Functional hand evaluations: a review. Am J Occup Ther 1987; 41: 158–63.

4. Fugl-Meyer AR, Jääskö L, Leyman I, Olsson S, Steglind S. The post-stroke hemiplegic patient. I. A method for evaluation of physical performance. Scand J Rehab Med 1975; 7: 13–31.
5. Smidt GL, Rogers MW. Factors contributing to the regulation and clinical assessment of muscular strength. Phys Ther 1982; 62: 1283–90.
6. Kattel BP, Fredericks TK, Fernandez JE, Lee DC. The effect of upper-extremity posture on maximum grip strength. Int J Ind Ergon 1996; 18: 423–9.
7. Innes E. Handgrip strength testing: A review of the literature. Aust Occup Ther J 1999; 46: 120–40.
8. Jones L. Dexterous hands: Human, prosthetic, and robotic. Presence 1997; 6: 29–57.
9. Jones RD. Measurement of sensory-motor control performance capacities: Tracking tasks. In: Bronzino JD ed. The biomedical engineering handbook 2nd ed. Vol. II. Boca Raton: CRC Press, 2000.
10. Blank R, Heizer W, von Voss H. Development of externally guided grip force modulation in man. Neurosci Lett 2000; 286: 187–90.
11. Vaillancourt DE, Slifkin AB, Newell KM. Visual control of isometric forces in Parkinson's disease. Neuropsychologia 2001; 39: 1410–18.
12. Kriz G, Hermsdörfer J, Marquardt C, Mai N. Feedback-based training of grip force control in patients with brain damage. Arch Phys Med Rehabil 1995; 76: 653–9.
13. Kurillo G, Bajd T, Mihelj M. Force tracking in two-oppositional grips. In: Hutten H, Krösl P eds. Proceedings of the 2nd European Medical and Biological Engineering Conference – EMBEC'02. Vienna: Druckerei Agath, 2002. II/1712–3.
14. Chadwick EKJ, Nicol AC. A novel force transducer for the measurement of grip force. J Biomech 2001; 34: 125–8.
15. Fowler NK, Nicol AC. A force transducer to measure individual finger loads during activities of daily living. J Biomech 1999; 32: 721–5.
16. Memberg WD, Crago PE. Instrumented objects for quantitative evaluation of hand grasp. J Rehab Res Dev 1997; 34: 82–90.
17. Kurillo G, Bajd T, Kamnik R. Static analysis of nippers pinch. Neuromodulation 2003; 6 (in Press).
18. Smith SS. Measurement of neuromuscular performance capacities. In: Bronzino JD ed. The biomedical engineering handbook 2nd ed. Vol. II. Boca Raton: CRC Press, 2000.