JOURNAL OF AUTOMATIC CONTROL, UNIVERSITY OF BELGRADE; VOL. 12:38-45, 2002 ©

Static Analysis of Two-Fingered Grips

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***Abstract* — In the paper a static analysis of two-fingered grips is presented. Importance of grasp analysis in human performance engineering and hand therapy is discussed and assessment methods are proposed. Two precision grips were examined in the study: *nippers pinch* and *tip pinch*. We have built a grip-measuring device assessing the endpoint forces of two-oppositional grips. The instrument developed is based on a robotic force-wrist sensor and designed to suit human fingers. Through the simultaneous use of an optical measuring system and the grip-measuring device, the finger positions and the grip force acting on the object were obtained. A static model of the hand was also developed. A recursive computational method was used to calculate the joint torques of the fingers from the measured coordinates and the endpoint force vector. The estimated joint torque corresponds to the amount of load on the tendon during isometric muscle contraction. The force output of the two grips considered is presented and compared in two healthy individuals. The calculated joint torques for the index finger and thumb are presented and the maximal values of the finger joint torques acquired in the study are shown.**

***Index Terms* — biomechanics, finger, grip force, hand, precision grip.**

I. INTRODUCTION

THE human hand is a complex biomechanical system that has the ability to adapt to many different tasks of everyday living. The main function of the hand is grasping but an important role is also an interaction with the environment. Different types of grasps are chosen based on the geometric properties of the object (e.g. shape of a cylinder, sphere, cone, thin plate, etc.) and the goal of the task, from which human select the final grasping approach [1, 2]. For many assignments, people developed different tools that promoted hand's functionality, but the role of the hand in daily activities is irreplaceable. The loss of hand's functionality from an injury or disease can in a great deal influence a person's way of everyday life [3, 4]. Different methods of rehabilitation and physical therapy can help such people regain a certain degree of functionality in their hands, while hand mobility assessment can help therapists with diagnosis and appropriate treatment [5, 6, 7].

The static force analysis of human grasp was performed in the research. A grip-measuring device was designed to record the force vector acting on the object in two-oppositional grips. The term "opposition" describes an abstract representation of human prehension where different parts of the hand (palm, finger pad and lateral surface) can apply appropriate forces in synergy to securely grasp an object [2, 5]. The best example of the opposition concept is represented by the role of the thumb opposing the remaining digits of the human hand in different precision grips [5, 8]. The study is focused on two-fingered precision grips, which are widely used in everyday activities where fine force control is required (e.g. writing, turning a knob, and other small-object manipulations).

Grasp analysis is important in the human performance engineering [7, 9], whether in the clinical assessment or in design of different tools and working environments. Measurements of grip strength provide substantial information on subject's neuromuscular capacity needed to perform different activities of daily living, work and sports [7]. Some grip studies focus only on the absolute value of the force acting on the object, giving thus somewhat less complete information about the properties of the grip applied. Capturing the grip force vector can give an additional knowledge of how the normal and tangential forces are being applied to the surface of the object by the fingers [3, 6, 10]. In case of a neurological condition or trauma, such information may be useful to determine deviations of one's grasp compared to a healthy subject [3, 10]. Numerical information gained from the hand measurements can provide some additional support to the existing hand evaluation tests [4]. The research of the complete grasp statics is important to understand the mechanics of the fingers and forces that act on finger joints during a grip applied. The finger joint torques act as actuators at the joints and describe the amount of load on the tendons during muscle contractions [11]. The information on the grip force and joint torques is also important in the design of different tools where the stress on the hand has to be minimized [6].

Two types of two-fingered grips were studied: *nippers pinch* and *tip pinch* [5]. Both can be characterized as precision grips [1, 5, 8], which are aimed to grasp and manipulate lightly weighted small objects. The *nippers pinch* is mainly applied to grasp objects of different shapes

The original manuscript received on the December 21 2001. The manuscript accepted in the final form on the April 9 2002.
The authors wish to thank Prof. Dr. Dejan Ravnik, Institute of Anatomy, Medical Faculty, University of Ljubljana, for the anthropometric data of the human hand.
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(e.g. a floppy disk, pencil) where more stability and sensory feedback on the object properties is required. The object is grasped between the finger pads of the thumb and index finger. When an additional precision is needed to accurately manipulate a very small object (e.g. a pin, paper clip), the *tip pinch* is used between the tips of the two fingers. This results in a higher stiffness of the object held, but sufficient sensory information is still available to maintain a stable grip. From the described characteristics of the two grips a better grip force control is expected in the *nippers pinch* because of a larger contact surface.

In our investigation the posture of the hand and the grip forces acting on the object were measured simultaneously. To retrieve finger positions during a grasp, optical measuring system was used [12]. The hand and the finger joints of the thumb and index finger were marked with markers to accurately capture their relative position to the object. The grip force was measured by the grip-measuring device (GMD) developed. From the results, finger joint torques were recursively calculated [13] by the use of the proposed static model of the human finger. The measured grip force and the joint torques were analyzed and compared in two healthy individuals to test the described assessment method.

II. METHODS

A. Model

Different models of the hand are suggested [3, 5, 10]. Each finger can be described as a serial manipulator attached to the palm. The three phalanxes of the finger are modeled as rigid segments connected with different types of joints. Four degrees of freedom (DOF) can describe the movement of each finger. Universal joint (2 DOF) models the flexion-extension and adduction-abduction of the metacarpo-phalangeal (MCP) joint. Two rotational joints (1 DOF) are used to model the flexion-extension of the proximal interphalangeal (PIP) and the distal interphalangeal (DIP) joints. A slightly different modeling approach applies to the thumb since it does not include the middle phalanx. The model of the three segments of the thumb includes the first metacarpal bone, proximal phalanx and distal phalanx. In our model four degrees of freedom were used to describe the movement of the thumb. The approximate mass of the segments of an average male human hand (with the total mass of 390*g*) was considered in the calculations. The masses used for the thumb were 60*g* for the proximal, 12*g* for the middle, and 10*g* for the distal segment. The masses for the index finger were 19*g* for the proximal, 6*g* for the middle and the same for the distal segment. The data were obtained from the Institute of Anatomy, Medical Faculty, University of Ljubljana. Both subjects in the study were selected to match an average male by the hand size. The center of mass for each segment was determined by an approximation of the phalanx with a cone-shaped homogenous rigid body, where the diameters of the knuckles were measured for each subject. This geometrical approximation was selected because it is simple for calculation (compared to an ellipsoid) and it considers an unequal mass distribution along the main axis due to different diameters at the segment ends. The influence of the anthropometric data variations is considered to be relatively small compared to the grip forces measured.

B. Experiments

To calculate the finger joint torques, the measurements of the fingertip force and position of the fingers, relatively to the object, are needed [11, 13]. Hand posture in a grasp was assessed by the optical measuring system OptoTrak (Northern Digital, Inc.). Forces acting on the object were measured through a specially designed grip-measuring device.

OptoTrak can accurately measure (with the accuracy of 0.1mm) the three-dimensional position of infrared markers placed in front of the system of three cameras. The relative position and orientation of the cameras are fixed, so the exact coordinates of each marker can be calculated from the known geometry. Two sets of cameras situated in the opposing direction were used in the study. The system must be calibrated before each measurement session with the help of a calibration plate. The position and orientation of the calibration plate placed in front of the cameras define the coordinate system in which the position of the markers is expressed. This coordinate system is also known as the world coordinate system (WCS) [13]. For convenience, all data measured were transformed into a local coordinate system of the sensor (SCS) to directly describe the grip force vectors measured. The sensor coordinate system is defined with the three markers applied to the upper surface of the grip-measuring device (Fig. 1) matching the internal coordinate system of the force sensor.

We also defined the hand coordinate system (HCS) to follow the relative position of the hand to the GMD. The coordinate system was placed onto the dorsal side of the subject's hand. The three markers on the hand defined the dorsal plane. The normal vector of the plane corresponds to the *Z*-axis of the coordinate system. The *Y*-axis is parallel to the flexion-extension axis of the metacarpophalangeal joint. The *X*-axis vector is determined from the other two axes to obtain an orthogonal system. The origin of the hand coordinate system is placed in the mass center of the triangle defined by the three markers (Fig. 1).

The rest of the markers were used to define the position of the joints and fingertip (Fig. 1). Since only two-fingered grips were considered, the markers were applied to the lateral side of the thumb and index finger. Three markers on the lateral side of a finger define the sagittal plane and its normal vector corresponds to the *Z*-axis of the finger joint coordinate system. The joint coordinate system of the segment *i* (JCS*i*) was placed at the distal end of the segment. The palm was considered as the segment #1, the proximal segment was denoted with the index #2, the middle with #3 and the distal segment with #4. The *X*-axis of each joint coordinate system was defined in the direction of a phalanx. To place the coordinate system on the last segment, an additional marker was required to define the tip of the finger. The *Y*-axis vector was then determined to obtain an orthogonal system. Each joint coordinate system (JCS*i*) was first placed into the corresponding marker position at the end of the segment and then translated along the *(-Z)*-axis for the half of the knuckle diameter to reach the center of the corresponding joint. The orientation of the joint coordinate system for the *i*-th joint of the finger *k* was expressed with a 3 by 3 rotation matrix ${}^k\boldsymbol{R}_0{}^i$ [13].

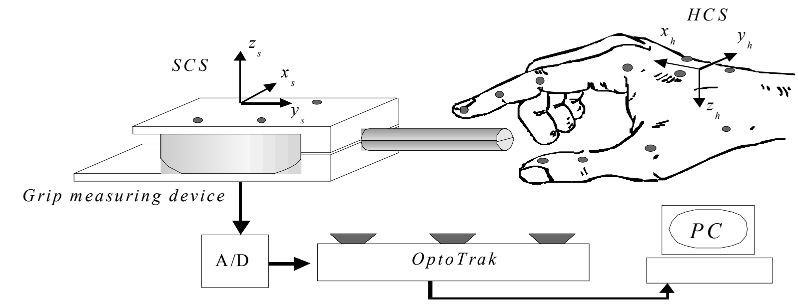


Fig. 1: Two-fingered grip assessment procedure was performed by use of the optical measuring system OptoTrak and a specially designed grip-measuring device. The hand and sensor were equipped with 14 infrared markers to define local coordinate systems and finger joint positions.

A grip-measuring device was designed to measure the endpoint forces of the two-oppositional grips. The instrument is based on the robotic force-wrist sensor JR3 (JR3, Inc.), which can sense forces in all three directions of its internal coordinate system. The sensor can measure forces up to 110N in the *X*- and *Y*-axis and 220N in the *Z*-axis. The force vector components were transformed into an analog voltage value and sampled with the frequency of 50Hz through the A/D unit of the optical measuring system OptoTrak. The measured data were collected by the use of a personal computer. In such a configuration both measuring systems were synchronized, so the data of the measured forces and positions of the finger joints were assessed simultaneously. The analysis of the results was performed off-line with Matlab software (The MathWorks, Inc.).

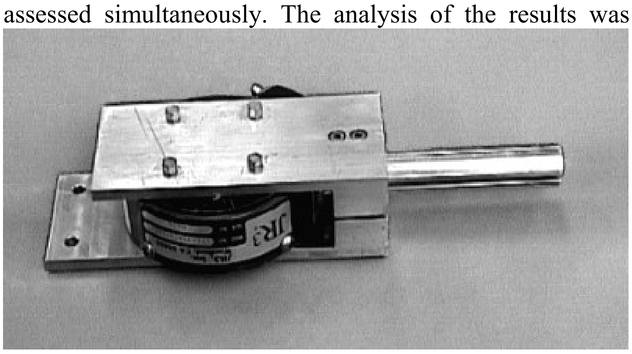


Fig. 2: Grip-measuring device (GMD) was designed to measure the endpoint forces of the two-oppositional grips. The instrument is based on a robotic force-wrist sensor. The two metal parts, which shape into a circular stick to fit human fingers, allow the transmission of the fingertip force to the sensory unit.

Since the cylindrical shape of the original sensor is not appropriate to be directly applied to human grasping, a special construction was designed to allow the transmission of the fingertip force to the sensory unit. The GMD consists of two metal parts that are shaped in the form of the letter "L" (Fig. 2). Two semi-circular shaped metal sticks are rigidly attached on the front side of the device, where the two "L" parts come close together. With the both metal parts attached to the sensor, the two semi-circular sticks shape into a circular stick. A certain degree of compliance allows the higher grip forces to be measured as well. When a person grasps the measuring stick, the grip force is translated to the sensor yielding the information on the force vector expressed in the sensor coordinate system. GMD can be fixed on a flat surface by two screws to prevent any external disturbances.

C. Analysis

A recursive computational method [13] was used to describe forces and torques acting on the segments of each finger. Contact with an object is defined by the endpoint force and considered as the point contact with friction. All the segments of the fingers were modeled as rigid. The previously described model of the hand was used in the calculations. The forces and the joint torques for every finger *k* were analyzed separately (*k*=1 for thumb and *k*=2 for index finger). All the vectors used in the equations are expressed in the coordinate system of the sensor (SCS). The necessary transformations were made by the orientation matrix multiplication [13].

The method is based on the Newton laws of statics. The equilibrium equations for forces are written for each segment *i*:

$$ {}^k\boldsymbol{f}_{i-1,i} - {}^k\boldsymbol{f}_{i,i+1} + {}^k m_i \boldsymbol{g} = 0 \qquad (1) $$

The forces that act on the segment *i* of the finger *k* (Fig. 3) are: the gravity force ${}^k m_i \cdot \boldsymbol{g}$ (where ${}^k m_i$ is the mass of the segment and $\boldsymbol{g}$ is gravity acceleration), the force ${}^k\boldsymbol{f}_{i-1,i}$ describing the force of the previous segment *i-1* acting on the segment *i* and the negative force ${}^k\boldsymbol{f}_{i,i+1}$ defining the action of the segment *i+1* on the segment *i*.

Next, the equilibrium equation for the torques acting on the segment *i* is written with regard to the origin of the joint coordinate system JCS*i* (also the center of a finger joint):

$$ {}^k\boldsymbol{T}_{i-1,i} - {}^k\boldsymbol{T}_{i,i+1} + {}^k\boldsymbol{r}_{gi} \times {}^k m_i \boldsymbol{g} - {}^k\boldsymbol{r}_{fi} \times {}^k\boldsymbol{f}_{i-1,i} = 0 \qquad (2) $$

In (Eq. 2) the vector ${}^k\boldsymbol{r}_{gi}$ connects the joint center with the center of mass for the segment *i* and ${}^k\boldsymbol{r}_{fi}$ connects the joint

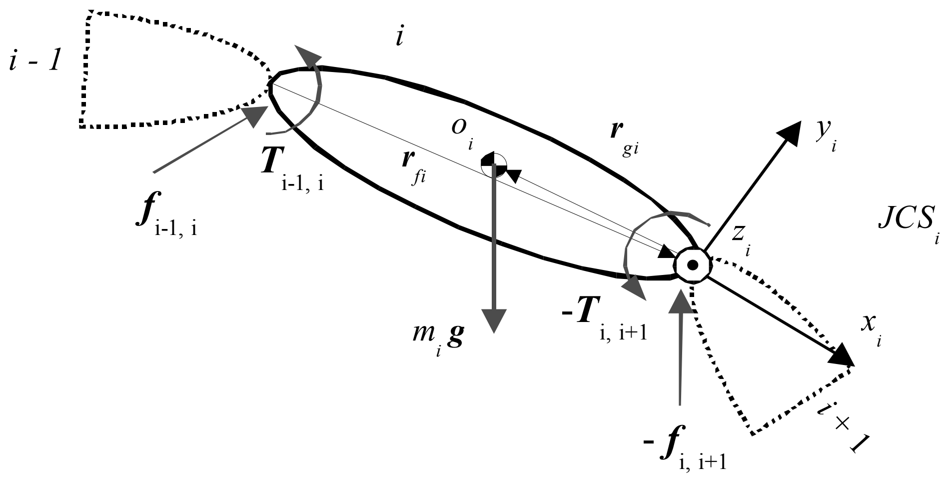


Fig. 3: Force and torque analysis of the i-th segment. Each finger was modeled as a set of rigid segments connected with joints.

center with the end of the segment *i*. The torque vector ${}^{k}\boldsymbol{T}_{i-1,i}$ describes the torque of the previous segment onto the segment *i*. ${}^{k}\boldsymbol{T}_{i,i+1}$ is the torque vector of the next segment acting on the segment *i*. The vector product ${}^{k}\boldsymbol{r}_{gi}\times{}^{k}m_i\boldsymbol{g}$ describes the effect of gravity force and ${}^{k}\boldsymbol{r}_{fi}\times{}^{k}\boldsymbol{f}_{i-1,i}$ is the torque caused by the force ${}^{k}\boldsymbol{f}_{i-1,i}$ acting around the origin with the moment arm ${}^{k}\boldsymbol{r}_{fi}$.

The force ${}^{k}\boldsymbol{f}_{i-1,i}$ and the torque ${}^{k}\boldsymbol{T}_{i-1,i}$ are derived from the equations (Eq. 1 and Eq. 2). In the first step of the recursive computation (*i*=4), the "next segment" is the grasped object so the negative force ${}^{k}\boldsymbol{f}_{i,i+1}$ equals the grip force measured with the force sensor ($\boldsymbol{F}_s$). The torque vector ${}^{k}\boldsymbol{T}_{i,i+1}$ equals zero since the fingertip is not attached to the object surface:

$$\begin{aligned} {}^{k}\boldsymbol{f}_{3,4} &= -\boldsymbol{F}_s \\ {}^{k}\boldsymbol{T}_{3,4} &= \boldsymbol{0} \end{aligned} \quad (3)$$

The force and torque vectors of the distal joint (*i*=3) are calculated from the fingertip force:

$$\begin{aligned} {}^{k}\boldsymbol{f}_{2,3} &= \boldsymbol{F}_s - {}^{k}m_3\boldsymbol{g} \\ {}^{k}\boldsymbol{T}_{2,3} &= -{}^{k}\boldsymbol{r}_{g3}\times{}^{k}m_3\boldsymbol{g} + {}^{k}\boldsymbol{r}_{f3}\times{}^{k}\boldsymbol{f}_{3,4} \end{aligned} \quad (4)$$

Next, the force and torque vectors of the medial joint (*i*=2) are calculated:

$$\begin{aligned} {}^{k}\boldsymbol{f}_{1,2} &= {}^{k}\boldsymbol{f}_{2,3} - {}^{k}m_2\boldsymbol{g} \\ {}^{k}\boldsymbol{T}_{1,2} &= {}^{k}\boldsymbol{T}_{2,3} - {}^{k}\boldsymbol{r}_{g2}\times{}^{k}m_2\boldsymbol{g} + {}^{k}\boldsymbol{r}_{f2}\times{}^{k}\boldsymbol{f}_{1,2} \end{aligned} \quad (5)$$

Finally, the force and the torque acting on the proximal joint (*i*=1) are determined:

$$\begin{aligned} {}^{k}\boldsymbol{f}_{0,1} &= {}^{k}\boldsymbol{f}_{1,2} - {}^{k}m_1\boldsymbol{g} \\ {}^{k}\boldsymbol{T}_{0,1} &= {}^{k}\boldsymbol{T}_{1,2} - {}^{k}\boldsymbol{r}_{g1}\times{}^{k}m_1\boldsymbol{g} + {}^{k}\boldsymbol{r}_{f1}\times{}^{k}\boldsymbol{f}_{0,1} \end{aligned} \quad (6)$$

The equations (Eqs 3 - 6) represent the static model of a finger. The calculation is performed separately for the thumb (*k*=1) and index finger (*k*=2). When considering the opposing finger in a grip, the endpoint force vector is oriented in the opposite direction.

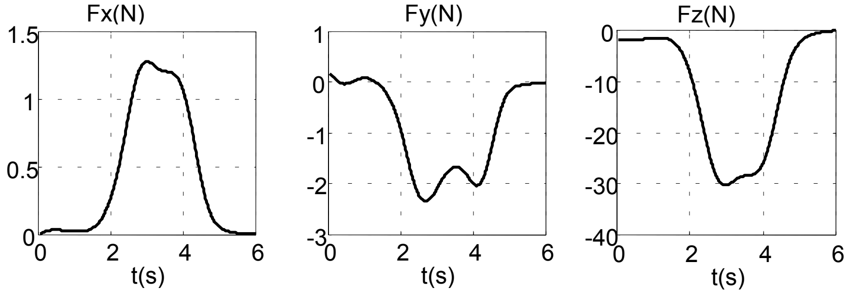
In order to obtain the force and torque vector acting in the center of each joint, we must transform the calculated vectors to the corresponding joint coordinate system (Eq. 7). The rotational matrix ${}^{k}\boldsymbol{R}_0^{i}$ describes the orientation of the *i*-th joint coordinate system:

$$\begin{aligned} {}^{k}\boldsymbol{F}_i^{i} &= ({}^{k}\boldsymbol{R}_0^{i})^{-1}\cdot{}^{k}\boldsymbol{f}_{i-1,i} \\ {}^{k}\boldsymbol{T}_i^{i} &= ({}^{k}\boldsymbol{R}_0^{i})^{-1}\cdot{}^{k}\boldsymbol{T}_{i-1,i} \end{aligned} \quad (7)$$

The described calculation approach was used to calculate the force and torque vectors acting on each joint from the measured fingertip force and finger joint positions. The method describes static conditions, but it can also be used to describe a dynamic situation, where the movements are slow and small.

III. RESULTS

Two types of precision grips were studied, *nippers pinch* and *tip pinch* (Fig. 4 and Fig. 5). They were performed by two right-handed healthy male individuals. Subject's hand was equipped with 11 infrared markers to define the finger joint positions as described in the previous section. The grasp was measured by OptoTrak to record the hand posture and by the grip-measuring device to obtain the grip force data. The GMD was rigidly attached to the table located in front of the OptoTrak cameras where the subject was seated on a chair with no additional support to the elbow. The subject was asked to first position the hand on the GMD without applying any pressure. Then he was instructed to perform each of the two grips with low (under 20N), medium (20 to 40N) and high level force (above



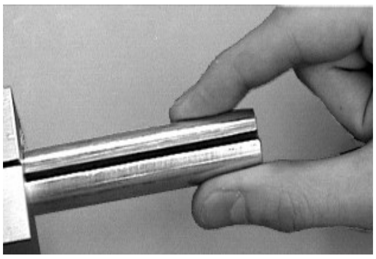
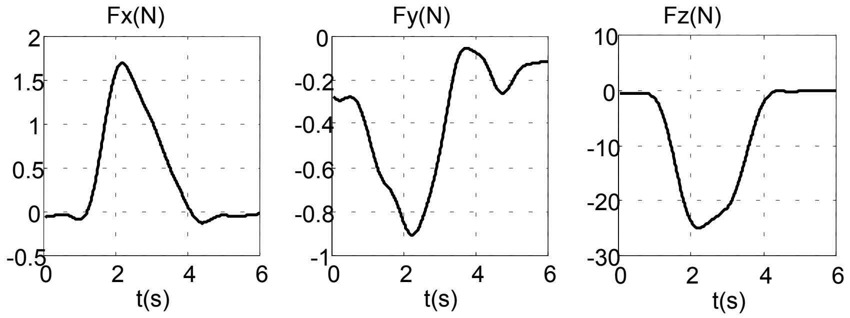


Fig. 4: *Nippers pinch* gives good sensory feedback allowing fine manipulation of small objects. Below is an example of the grip forces as assessed in the first subject. The maximal force component is perpendicular to the finger



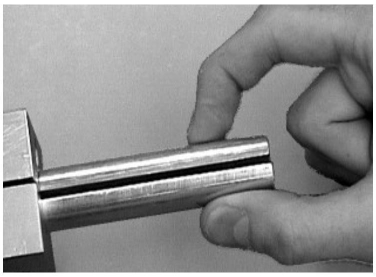


Fig. 5: *Tip pinch* gives less sensory feedback since the contact surface is smaller than in *nippers pinch*. Below are the grip forces as assessed in the first subject. The maximal force component is perpendicular to the finger pads.

40N), keep it steady for a moment and then slowly release the grip. The whole session lasted approximately 6 seconds. In the paper, the results of the mid-level grips are presented (Figs. 4 & 5, Table 1). In some cases, the OptoTrak data were missing due to an inadequate finger position or the applied force was too low or too high with respect to the range of measurement of the force sensor used.

Three successful trials were considered for each subject. The results were analyzed off-line on the personal computer using Matlab software. The measured force data were filtered with IV. order Butterworth filter (cut-off frequency 5Hz, sampling frequency 50Hz).

The measured grip forces of the *nippers pinch* (Fig. 4) and the *tip pinch* (Fig. 5) show a bell-shaped profile along the *Z*-axis of the sensor coordinate system, reaching the maximal values between 20N and 30N (Table 1). The shapes of the other two components of the grip force vector differ from the bell-shaped profile reflecting that the force control in the tangential directions to the finger pads is lower. The tangential force components of the *tip pinch* tend to fluctuate more (Fig. 5).

Both grips are used to manipulate small objects (e.g. pencil, paper clip) where fine grip-force control is required. Due to a smaller contact surface providing less sensory feedback information, the fingertip force of the *tip pinch* is more difficult to direct, resulting in a less stable grip. The *tip pinch* is more appropriate to grasp objects of smaller diameters (e.g. needle) compared the finger size.

The recursive computation was used to obtain joint torques from the measured grip force and finger joint positions. The calculation was made separately for the thumb and index finger. Only the joint torque vector components that apply to the proposed static model of the finger were considered for each grip and the maximal values were recorded (Table 1).

The four torques, which apply to the static model, were calculated for each finger (k=1 for thumb and k=2 for index finger): the torque (${}^{k}T_{1y}$) around the adduction-abduction axis of the MCP joint and the three torques (${}^{k}T_{1z}$, ${}^{k}T_{2z}$, ${}^{k}T_{3z}$) around the flexion-extension axes of the MCP, PIP and the DIP joint. The torques assessed in the thumb act around the carpometacarpal (CMC), metacarpo-phalangeal (MCP) and inter-phalangeal (IP) joint.

The calculated finger joint torques have a bell-shaped profile (Fig. 6, Fig. 7). The results (Table 1) show that the torque values around the flexion-extension axes of both fingers are much higher than the adduction-abduction torques. Both grips are predominantly directed towards the object's surface so there is less force component activity along the surface in either direction. Comparing the results of both grips in the two individuals (Table 1) indicates that the abduction of the two fingers is higher in the *nippers pinch* (Fig. 6) than in the *tip pinch* (Fig. 7). The results (Table 1) show that both subjects had similar values of the finger joint torques for the same type of grip, which results from a very similar posture used in both cases. The difference in torque results comes from different moment arms (finger segment lengths) and a slightly different force applied to the grip-measuring device. Comparison of the torques shows that the load in the index finger joints is considerably higher than in the joints of the thumb (Table 1).

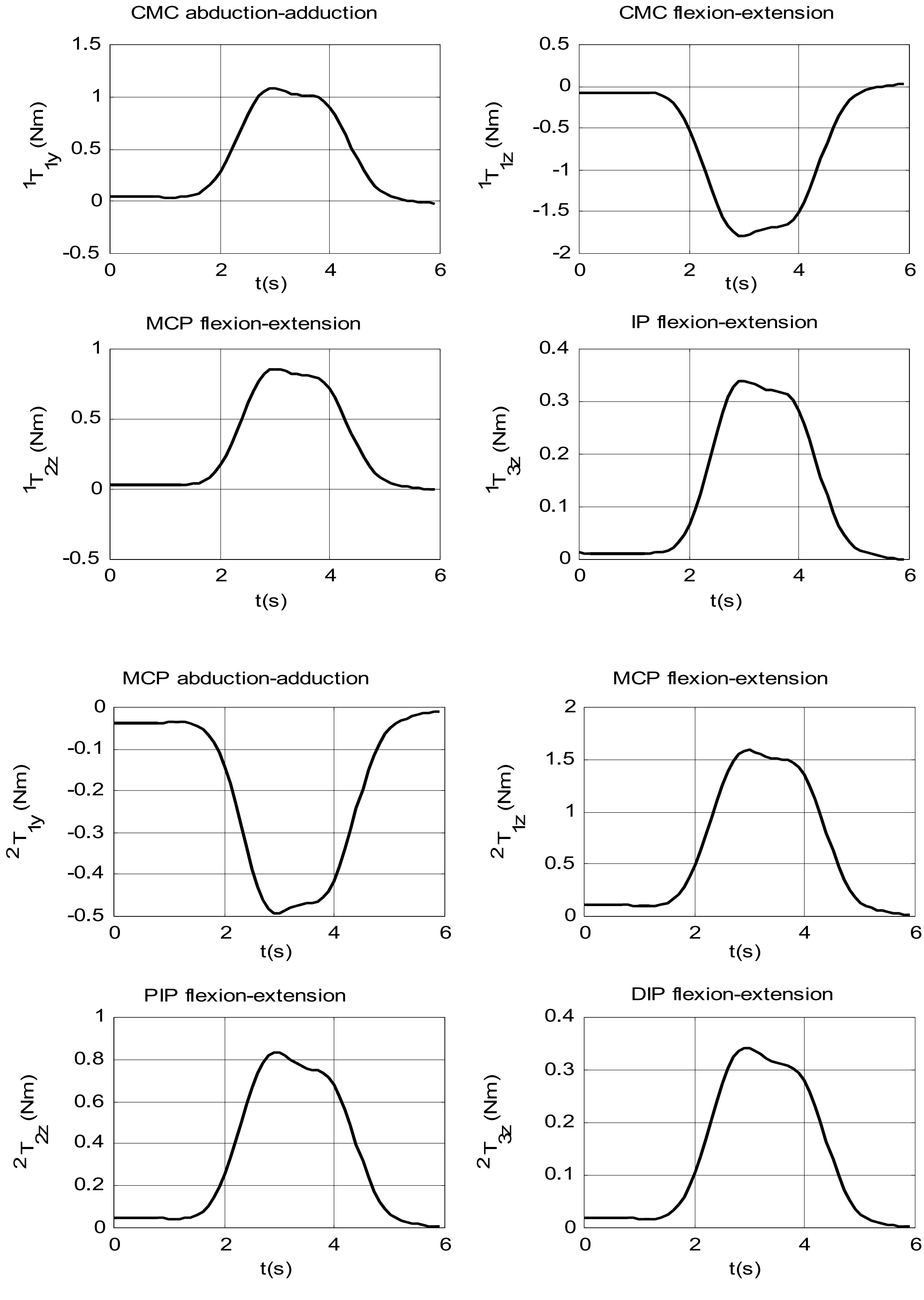


Fig. 6: The calculated finger joint torques in *nippers pinch* for the thumb (above) and index finger (below) have a bell-shaped profile. Four torques were observed for each finger: the torque ($^kT_{1y}$) around the abduction-adduction axis of the proximal joint and the three torques ($^kT_{1z}$, $^kT_{2z}$, $^kT_{3z}$) around the flexion-extension axes of all three joints.

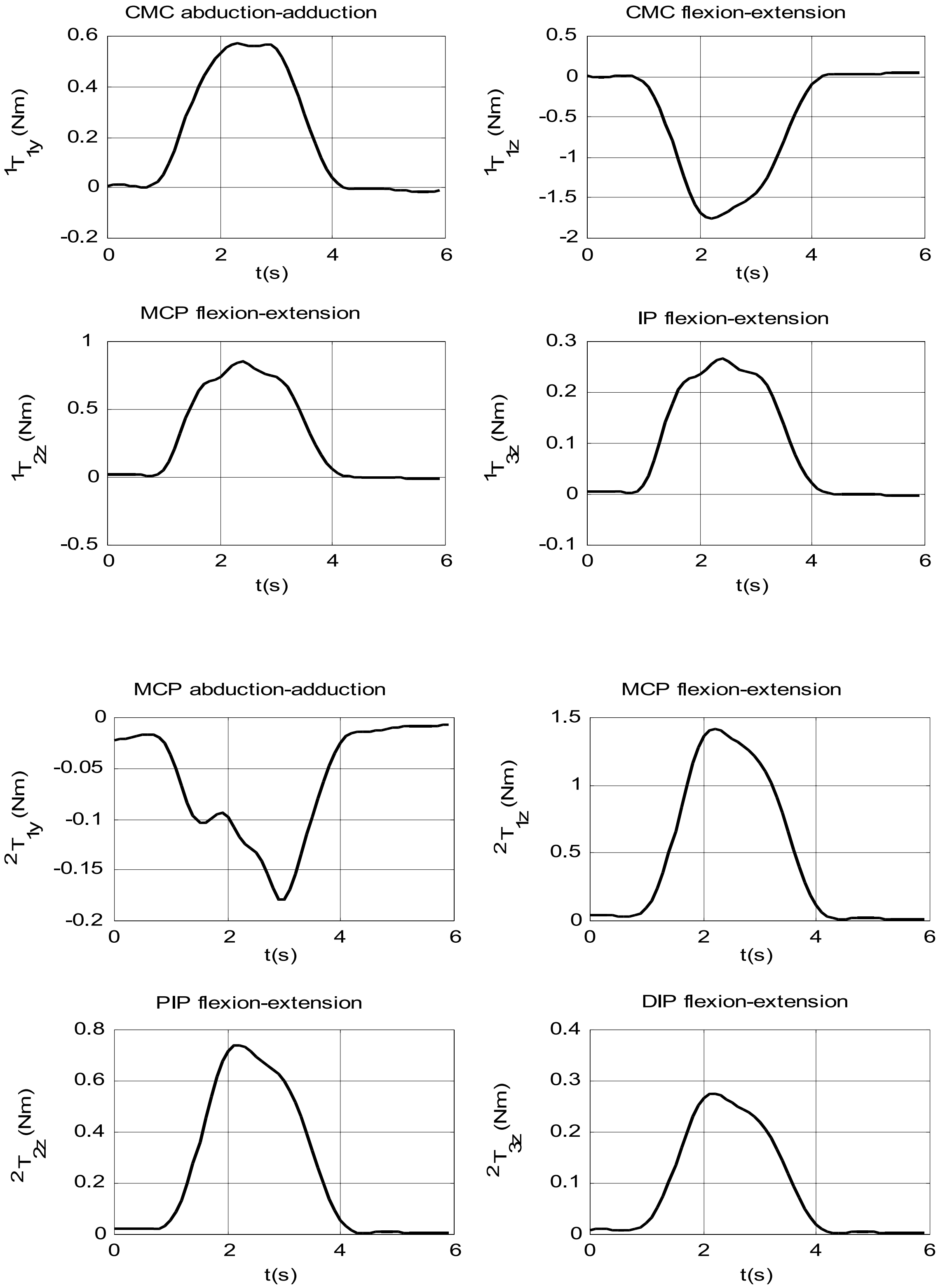


Fig. 7: The calculated finger joint torques in *tip pinch* for the thumb (above) and index finger (below) have a bell-shaped profile. Four torques were observed for each finger: the torque ($^kT_{1y}$) around the abduction-adduction axis of the proximal joint and the three torques ($^kT_{1z}$, $^kT_{2z}$, $^kT_{3z}$) around the flexion-extension axes of all three joints. Abduction-adduction torque of the fingers is significantly lower than in the *nippers pinch*.

		GRIP FORCE (N)			JOINT TORQUES OF THE THUMB (NM)				JOINT TORQUES OF THE INDEX-FINGER NM)			
		F_X	F_Y	F_Z	$^1T_{1Y}$	$^1T_{1Z}$	$^1T_{2Z}$	$^1T_{3Z}$	$^2T_{1Y}$	$^2T_{1Z}$	$^2T_{2Z}$	$^2T_{3Z}$
Nippers pinch	S1	1.3	-2.3	-30	-0.50	1.55	0.82	0.34	1.1	-1.7	0.81	0.34
	S2	-1.8	1.3	-28	-0.60	1.40	0.61	0.25	1.2	-1.5	0.94	0.35
Tip pinch	S1	1.7	-0.9	-24	-0.18	1.40	0.75	0.28	0.6	-1.7	0.80	0.25
	S2	-2.6	-2.0	-20	-0.31	1.00	0.50	0.20	0.7	-1.2	0.82	0.27

Table 1: The maximal values of the finger joint torques and the grip force components compared for nippers pinch and tip pinch in the two subjects (S1 and S2). The values of the finger joint torques indicate that the adduction of the fingers is considerably lower in the tip pinch than in the nippers pinch. The results also show that the load on the joints of the index finger is considerably higher than the load on the thumb joints in two-fingered grips.

IV. CONLUSION

The purpose of this study was to present the static analysis of two-fingered grips. The OptoTrak system was used to capture the hand posture along with the grip-measuring device, which was aimed to measure the grip forces. From the measured fingertip force and finger joint positions, the finger joint torques were calculated. The joint torques describe the amount of load on the tendons during the grip applied. The study was focused on two types of precision grips: *nippers pinch* and *tip pinch*. Both of the grips are used to manipulate small objects and require an accurate grip force control. From the calculated finger joint torques, the amount of load at the joints was compared between the two grips. The results were compared in two healthy individuals showing that the method can be useful for the analysis of human grasping.

The assessment should be performed on several healthy subjects to obtain the reliable results needed for an objective grip evaluation. The results have shown that the repeatability of the grip force between the subjects needs to be improved with a visual feedback (e.g. from the computer screen) in order to produce the gripping forces as required by the examiner. The assessment of isometric grip forces by the GMD with visual feedback could offer useful results for the analysis of sensory-motor control in tracking tasks [9]. The subject would be presented with a graphical display showing the target signal and the subject's grip force response. With a modification of the GMD, grasps of different objects could be simulated. Variously shaped endpoint objects (e.g. in the shape of a disk, sphere, cylinder, etc.) could replace the measuring stick in order to evaluate the tracking performance and sensory-motor control of grip forces applied in different hand postures. Such method would provide insight into human neuromuscular and sensory-motor performance in lower-level tasks that require hand manipulation [9]. The knowledge of forces acting on differently shaped objects is also important in ergonomics where different products and tools need to be adjusted to human grasp to minimize discomfort and injuries of the hand [1, 7].

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