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Movement Analysis in Parkinson's Disease

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***Abstract*—**We analyze hand dexterity in Parkinson's disease patients (PD) and control subjects using a natural manual transport task (moving an object from one place to another).

Eight PD patients and ten control subjects performed the task repeatedly at maximum speed both in OFF and ON medicated status. The movement parameters and the grip and load forces were recorded by a single optoelectronic camera and force transducers built in the especially designed object. Using the force and velocity signals, ten subsequent phases of the transport movement were defined and their durations were measured. The outline of 3D optical measurement is presented to obtain more precise movement trajectory.

***Keywords*—**Manual transport, Movement phases, Parkinson's disease.

I. Introduction

HAND motor function is easily disturbed in neurological disease and this may represent a serious handicap. Lesions in different structures of the central and peripheral nervous systems cause specific disturbances of hand function in the resting position (e.g. resting tremor and dystonia in Parkinson's disease), when movement is initiated (Parkinson's disease), in reaching a target (cerebellar disturbance) etc. It can be assumed that different lesions would influence also the various phases of a manual transport movement, such as: the forming of the grip, establishing the grip, lifting the object, the transport phases, and placing the object on the target point. A method based on a simple manual transport act could therefore be useful for an objective description and quantification of certain hand movement disturbances.

A manual transport movement is built up by a sequence of isotonic and isometric phases. It consists of reaching for an object (isotonic phase), touching and grasping it (isometric phases) and transporting it to a final goal position (isotonic phases). In the same way release of the grip and return of the hand to its start position can be described. These phases have mostly been studied separately or in short sequences, e.g. reaching only, reaching and grasping [1]-[3].

In the present study we examined a natural manual transport task (transporting an object from one place to another) in patients with PD.

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II. Methods

Eight patients with the diagnosis of Parkinson's disease (PD) and ten healthy subjects were examined. The PD patients were tested both in the medicated (ON) and the unmedicated (OFF) state, all of them in OFF first. The OFF state was achieved more than 12 hours after withdrawal of antiparkinsonian medication while the ON state 1.5 hour after taking the usual medication again.

The subject sat with the right forearm comfortably resting on the table and the hand on a pressure sensitive pad (start position of the hand – A, Fig. 1).

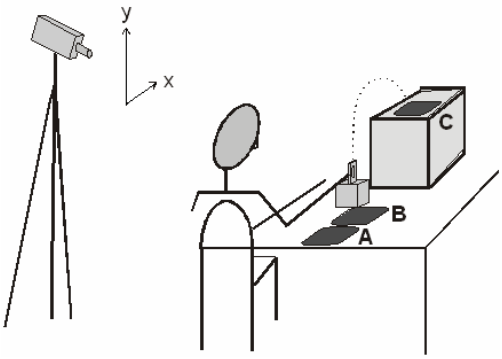

Fig. 1 Experimental setup: Initially the hand was resting on a pressure sensitive pad (A) and the object was placed 10 cm in front of the hand (B). After the instruction to move, the subject reached for the object, picked it up using the precision grip and transported it onto a stand (C), where the grip was released. Then the hand returned to position A

The object was placed on the table as well, 10 cm in front of the resting hand (start position of the object - B). After a verbal instruction the subject moved his/her hand towards the object, picked it up using the precision grip (between the tips of the thumb and the index finger) and transported it forwards and upwards onto a stand, where the grip was released (goal position of the object - C). Then the hand returned to position A. Having touched the pad, the hand started to move immediately again, picked up the object from the stand (C) and transported it backwards to the start position (B). Leaving the object there the hand returned to the pad (A). This cyclic procedure was repeated at maximum speed as many times as possible during a recording session of 20 s. Thus, the number of repetitions (lifts) was different for each subject (3 to 10 lifts). Two test arrangements were used that differed in the

goal position of the object: Low lift (28cm distance between start B – target CLL) and High lift (56cm distance between start B – target CHL), see Fig. 2.

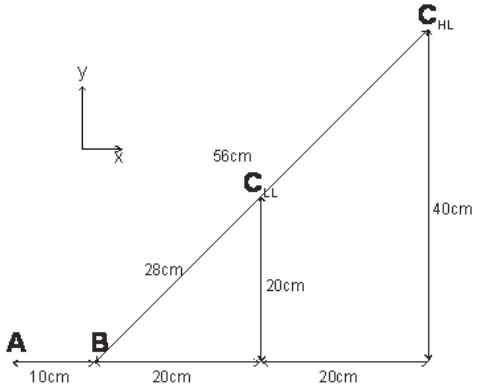

Fig. 2 Low lift versus high lift: Two test arrangements were used that differed in the goal position of the object (CLL in Low lift and CHL in High lift). The start position of the hand (A) and the start position of the object (B) were the same in both Low and High lift. The scheme shows the sagittal plane in which the movement was performed

III. Movement and Force Recording

The movement of the hand was recorded by an optoelectronic camera (Mac Reflex). The camera recorded two-dimensional displacement of reflective, passive markers attached to the hand and to the object. Three infrared light reflective markers were placed on the hand (dorso-radial part of the wrist, distal phalanx of the index finger and the thumb), one was attached to the object. Two static reference markers were situated in the space.

An infrared flash, built in the camera, illuminated the measurement area in regular intervals. The infrared light was thereafter reflected by the markers and recorded in the camera. The camera contained an optical filter, which cut off the visible part of light spectrum in favour of the infrared light. The filter was thus designed to display only reflective markers and nothing else in the image. It enabled recording during daylight while excluding artifacts. The exposure time was 800 µs, and the sampling frequency was 50 Hz.

The marker positions were extracted by the camera resolution system and resulting x and y values were delivered for each frame. The raw data file containing coordinates of the markers in time was stored in the computer. The path of the object movement and the spatial orientation of the hand were subsequently reconstructed from the spatio-temporal coordinates of the markers (offline processing).

Velocity and acceleration of the object were calculated from the movement data delivered by the camera (=first and second derivation of the trajectory).

The grip force (normal to the grip surfaces) and the load force (vertical lifting force) were recorded by force transducers, built in an especially designed object. It was a cube (75 mm x 75 mm x 75 mm) with parallel grip surfaces (25 mm diameter, 4 mm apart) on its top. The output signals of the transducers were digitized by a 12-bit AD-converter. Sampling frequency of the force sensors was 400 Hz.

Forces acting on the object are shown in Fig. 3. The object did not permit recording of the horizontal movement force. Instead, this force was calculated from movement data (horizontal movement force = horizontal acceleration × mass). The object also measured a Press force that corresponded to

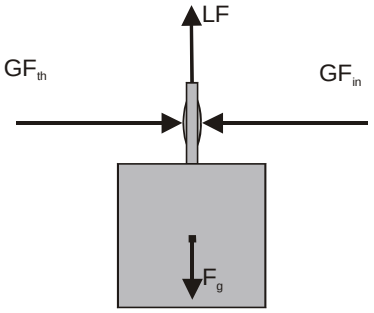

Fig. 3 Forces acting on object, in x-y plan: LF – load force (vertical lifting force), GF – grip force exerted from the thumb (th) and index finger (in), Fg– gravitational force

pressure applied against the table surface while lifting or placing the object.

The signals from the camera (vertical position, velocity and acceleration of the object in time), from the pressure sensors (load force and grip force) and from the pressure sensitive pad were used to determine the beginning and the end of the ten subsequent movement phases (Fig. 4). An original recording of a healthy control subject and a PD subject is shown in Fig. 5.

Using the described test arrangement and the individual movement phases we intended to examine separately the different qualities of the abnormal movement performance in PD. These were possible disturbance of the precision grip establishment (corresponding to preloading and loading phases), the ability to accelerate the movement (acceleration phase and indirectly transport-1 phase), braking the downward movement and release of the precision grip (replacing and postreplacing phases). The basic idea is that a disturbed action during a specific phase will cause longer duration of that particular phase compared to that of controls [5], [6].

The longer duration of some phases may also be caused by longer trajectory of movement. Using one optoelectronic camera we are able to measure only movement on one explicit plane. In this case we cannot discover the prolongation due to the trajectory of movement. To overcome this inaccuracy we need a three dimensional measurement of movement. Using 3D movement analysis in Parkinson's disease we proposed the system with two cameras and made prime experiments concerning its accuracy and robustness.

IV. Outline of 3D Movement Analysis

There are different methods how the 3D movement analysis

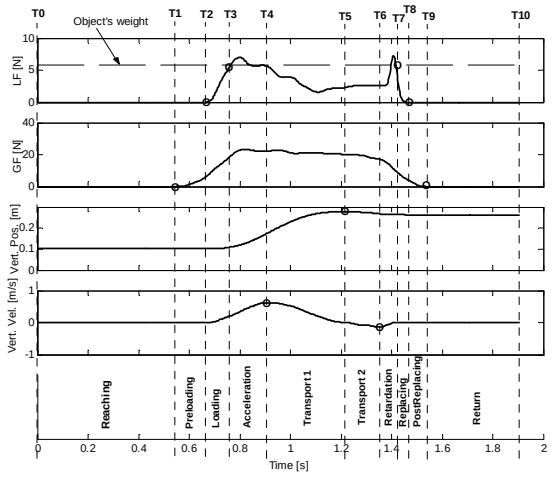

Fig. 4 Movement phases: Signals to detect the Manual transport phases (load force LF, grip force GF, vertical position and vertical velocity of the object). T0-T10 indicate the beginning and/or the end of each phase. T0: the hand begins to move starting from an initial position, T1: increasing grip force (GF), T2: increasing load force (LF), T3: load force exceeding the object's weight, T4: maximal vertical velocity (Vert. Vel.) of object, T5: maximal vertical position (Vert. Pos.) of the object, T6: minimal vertical velocity of the object, T7: load force lower than the object's weight, T8: zero-crossing of load force, T9: zero-crossing of grip force, T10: hand returned to the initial position on the table

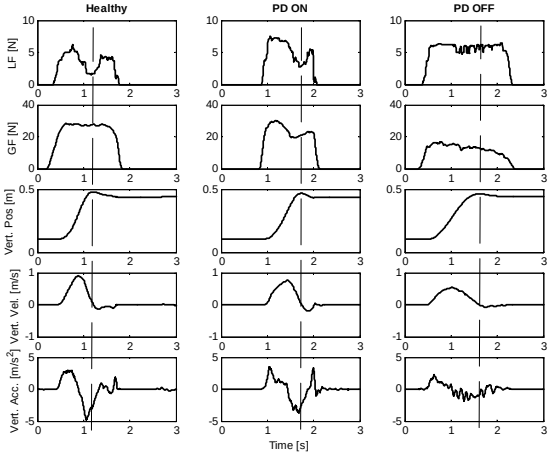

Fig. 5 A typical recording: A typical example of kinetic and kinematical signals (load force LF, grip force GF, vertical position, vertical velocity and vertical acceleration of the object) in a healthy control subject and a Parkinson patient in medicated (PD ON) as well as unmedicated (PD OFF) state. Dashed lines indicate the moment of the maximal vertical position of the object

may be performed. Common tracking systems use magnetic or ultrasonic trackers as well as mechanical devices. The drawbacks of these systems are their principles of work. Typically, the patient has to be linked to a measurement instrument, either by cable or by a mechanical linkage, which is more restraining. Furthermore, while mechanical tracking systems are extremely precise, magnetic and acoustic tracking systems suffer from different sources of distortions. For this reason, an optical tracking is an alternative solution which overcomes many of the drawbacks of the mentioned systems. However it requires always a free line of sight between the markers and cameras. It does not involve any magnetic field for determination of position data and consequently does not permit any deformation of these data in the presence of metallic structures. Their principle is based on the analysis of 2-dimensional projections of image features received by cameras.

For reconstruction of 3D coordinates of moving points we need at least two views, where the coordinates of the corresponding image points are visible. The reason that at least two views are needed is that one view determines only a line on which the object point must lie, but not the exact position. The second view determines a second line intersecting the first one in 3D space giving the exact object point position.

Before the camera system can be used to track markers (placed on the patient's hand and to the object), the system first needs to be calibrated. This is done by placing a known calibration frame in front of the cameras and by running the calibration software on the computer. Several methods for camera calibration were presented in literature [20], [21]. For our prime experiments we have used Matlab toolbox for performing calibration procedure based on direct linear transformation (DLT) [20]. This mathematical model was used in order to calculating intrinsic (focal length, location of the image center, effective pixel size, distortion coefficient of the lens) and extrinsic (rotation matrix, translation vector) camera parameters.

When the camera system is calibrated the marker recognition algorithm follows. Positions of the markers in the acquired images can be detected manually (off line processing) or by some of the auto-detection algorithms such as [18] or [19]. The following step in 3D measuring of moving markers is establishing the correspondences between pairs of points (positions of markers) from both of the images purchased by cameras.

Given the cameras' internal parameters and relative pose (as result of the calibration) as well as the corresponding image points the 3D position of markers may be computed for the sequences of images.

V. Discussion and Conclusion

Hand dexterity in Parkinson's disease patients were analyzed based on mean durations of all movement phases. Group mean and pooled standard deviation were considered with respect to the individual number of lifts. This was done for the patients in OFF, in ON and the controls. The difference between the PD-OFF and the control groups was established statistically using the Mann-Whitney U-test, ON versus OFF using the Wilcoxon matched pairs test [8].

The transport capabilities were impaired differentially – while acceleration and reaching sufficient height during the lift were disturbed in PD subjects, transport of the object

towards the target position and placing were almost normal (precision as well as durations of the corresponding phases). Fewer disturbances were observed when releasing the grip.

Dopaminergic medication improved only specific hand skills – especially establishment of the precision grip (both preloading and loading phase durations shortened). The effect of treatment was seen using a long movement path (High lift) while using a short path (Low lift) no difference between PD-off and PD-on was observed.

A. Precision Grip

Establishment of the precision grip is a complex act comprised of two phases – the preloading phase where the grip force increases until the load force starts and the loading phase where both the grip force and the load force increase simultaneously until lift-off. In the present study both of the preloading and the loading phases were prolonged in PD-off and improved after medication.

B. Transport

The transport part where the object is moving consists of four phases: acceleration, transport-1, transport-2 and retardation. During the initial two phases the object moves upward and these phases are dependent on muscle activity. Having reached the appropriate height, the hand with the object moves passively towards the target (transport-2). The muscles are reactivated during the retardation phase.

Initially, the subject has to accelerate the object to overcome gravity (acceleration phase) and to reach sufficient height before approaching the target position (transport-1 phase). Both these phases were prolonged in PD subjects.

During transport-2 and retardation phases the object approaches the target. Muscle activity is increasing in the latter phase in order to break the movement downwards and place the object gently. Neither transport-2 nor the retardation phases were prolonged in PD during Low lift, while the retardation phase was prolonged in High lift.

C. Placing

We studied loosening the grip in terms of two phases durations – replacing and postreplacing. Only the replacing phase was prolonged in PD-off, both during High and Low lifts. Replacing phase started when the object reached the goal position and was ended by cancelling the load force while still gripping the object. Its duration corresponds to how fast the subject is able to terminate the load force acting on the replaced object. At the same time the grip force decreased, thus again coordination between grip and load force was needed. A similar feature, a delay in arresting a movement belongs to the common clinical signs of Parkinson's disease [17].

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