Gait & Posture 42 (2015) 472–478

Contents lists available at ScienceDirect

Gait & Posture

journal homepage: www.elsevier.com/locate/gaitpost

Upper extremity coordination strategies depending on task demand during a basic daily activity

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ARTICLE INFO

Article history:
Received 11 November 2014
Received in revised form 23 July 2015
Accepted 24 July 2015

Keywords:
Upper extremity
Evaluation
Kinematic analysis
Activities of daily living
Electromyography
Performance test

ABSTRACT

Injury conditions affecting the upper extremity may lead to severe functional impairment and an accurate evaluation is needed in order to select the most effective treatment in a rehabilitation program. This study focused on simultaneous electromyographic and kinematic analysis to assess movement patterns of upper extremity during a basic daily activity, considering different demands existing within the task.

Twenty-five healthy subjects, average age 19.8 ys SD 1.7 ys, with no upper extremity impairment, were assessed by means of electromyography (EMG) and a 3D motion capture system while performing a task that required reach, transport and release. Integrated EMG (iEMG), timing of muscle onset and active range of motion (AROM) were calculated for each subject. Data were compared within each phase and between the three phases and a repeated measure ANOVA was used for statistical analysis.

We found early activation of upper trapezius associated with high activity of serratus anterior for proximal stability while anterior deltoid and triceps brachii performed shoulder flexion and elbow extension, in Reach phase. In Transport phase there was early and higher activation of upper trapezius, higher muscle activity of almost all muscles and increased AROM of all joints. No change in flexion/extension wrist posture with increased forearm muscles activity were identified as the main control strategy to keep optimal grasping. Triceps brachii was found to act as an important synergist in shoulder abduction and extension in free load conditions. Such information can lead clinicians to more specific assessment and subsequent better intervention in upper extremity rehabilitation.

1. Introduction

Human survival is directly related to movement and, specifically, the upper extremity is the basis of our fine motor skills, which are extremely important in the proper execution of activities of daily living (ADL) such as feeding, dressing and personal care/hygiene [1]. Injury conditions that affect the upper extremity, such as fractures, tendinopathies or nerve entrapments, may lead to severe functional impairment. An accurate evaluation is required in order to select the most effective treatment in a rehabilitation program.

Manual muscle testing, range of motion measured with a goniometer and threshold sensibility assessment are common techniques used in clinical practice to provide valuable information about the patient's physical condition but they do not reflect the functional status. Therefore, it is imperative to conduct specific functional assessment, which can be done through performance tests or questionnaires [2,3]. Performance tests usually simulate ADL or work situations and are able to measure dexterity and coordination. They are generally standardized, which means that the method, equipment, and sequencing described in the test instructions must be strictly followed [3].

In addition to these tools, electromyography (EMG) and kinematic analysis have been widely used to provide highly objective information on human movement [4–15]. Surface EMG

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http://dx.doi.org/10.1016/j.gaitpost.2015.07.061
0966-6362/

has been used in biomechanical studies [4] for the assessment of muscle activity in upper extremity motor control [5], sports motion [6], rehabilitation exercises [7,8] and neurological conditions [9,10]. To similar purpose, kinematic analysis has been performed in order to assess dexterity in ADL [11], hand coordination [12], sports motion [6] and neurological conditions such as cerebral palsy [13,14], stroke [9,15] and facioscapulohumeral dystrophy [10].

Kinematic analysis provides relevant information about range of motion (ROM), velocity and angular acceleration. Nevertheless, it does not assess the mechanisms underlying movement. Upper extremity motion is a complex arrangement requiring a wide range of joint angles and concurrent coordinated activation of multiple muscles. Despite there being complementing data, little has been reported about simultaneous assessment of EMG and kinematic patterns. Furthermore, de los Reyes-Guzmán et al. [16] carried out a review on quantitative assessment based on kinematic measures during upper extremity movements and found a shortage of studies regarding basic daily activities.

Therefore, the aim of this study was to investigate movement patterns of the upper extremity along with muscle activity during a basic daily activity considering different demands within the task. The results must contribute to a better understanding of specific adaptations of control strategies during a basic daily activity task and may help professionals in planning and evaluating treatment programs and techniques.

2. Methods

2.1. Participants

Twenty-five healthy subjects (5 men, 20 women; mean age ± SD, 19.8 ± 1.7; all right dominant) participated in this study. They had no history of injury or trauma in the upper extremity. The sample size calculation was carried out by means of the software GraphPad StatMate® (version 2.0, GraphPad Software, Inc., USA), using the standard deviation of electromyographic activity (μV) from extensor carpi radialis longus and brevis while conducting a grasping task, in a pilot study conducted with 16 volunteers. This muscle was chosen because of its important role in stabilizing the wrist during the functional use of hand. The sample power was 90%. All volunteers gave written informed consent. Ethical approval was obtained (Research Ethics Committee of Clinical Hospital of Ribeirão Preto, Medical School of University of São Paulo, protocol number 777.193/2014). The study followed the guidelines of the Helsinki protocol.

2.2. Task

The task "Pour Water" belonging to the Elui Functional Test of the Upper Extremity – Elui Test [17] was selected for this study. This test was developed based on standardized pre-existing tests and was created in order to evaluate the most common grips used in everyday living. It is an affordable test that can be easily applied, and this specific task was chosen because of its movement demands and also for presenting excellent inter-rater and test–retest reliability [17].

Materials required for this task were: 1-litre plastic pitcher full of water and another one empty, both with side handle, measuring approximately 13 cm tall and with spout for pouring; a table with steel frame and wooden plate with demarcations regarding the placement of start and end position of the hand; and a chair without armrests, with backrest and adjustable height. Both pitchers were placed on the opposite side to the hand to be tested, meaning that the starting one, which was full, was the farthest pitcher from the volunteer.

Before performing the task, the volunteer was seated with his testing hand lying on the table at the indicated place and the other hand remained on the left thigh. After the verbal command "go", the sequence of movements was as follows: taking the full pitcher, moving it following the borders of the table, pouring the water into the other pitcher, placing the empty one in the place where it was at the start of the task and finally returning the hand to its initial position. Volunteers were instructed to perform the task at their own comfortable speed. The task was repeated 3 times, but only the third one was taken for further analysis due to motor learning issues. [17]

Before processing data, the task was divided into 3 phases according to different demands of movement, named as follows: phase 1 – Reach phase, phase 2 – Transport phase and phase 3 – Release phase. The start and end points of each phase were determined by observing hand and pitcher markers shifting on the displacement graph of the Vicon Nexus™ Software. Fig. 1 illustrates the task and describes different demands identified within each phase.

2.3. Data recording

Movements were recorded with a Vicon™ (Oxford Metrics, UK) motion capture eight-camera system operating at a frequency of 200 Hz. Data was filtered using a fourth-order Butterworth filter with a 5 Hz cutoff frequency. Reflective markers were attached onto subject's body following the model used by Murgia et al. [18] for shoulder, elbow and wrist. For the hand, an adaptation was made from Carpinella et al. [19]. Table 1 shows the names and anatomical landmarks used to attach the markers.

Muscle activity was measured using surface EMG (Trigno™ Wireless System, Delsys, USA), collected at a sample rate of 2000 Hz. Data from upper trapezius muscle (UT), serratus anterior (SA), anterior deltoid (AD), middle deltoid (MD), posterior deltoid (PD), pectoralis major (PM), biceps brachii (BB), triceps brachii (long head) (TB), flexor digitorum superficialis (FDS), flexor carpi ulnaris (FCU), extensor carpi radialis longus and brevis (ECRLB) and extensor carpi ulnaris (ECU) were recorded. The skin was prepared by shaving and cleaning with alcohol, in accordance with SENIAM [20]. Sensor placement of UT, AD, MD, PD, BB and TB was performed according to SENIAM [20], while sensor placement of SA, PM, FDS, FCU, ECRLB and ECU was performed according to Perotto [21].

2.4. Data processing and statistical analysis

Kinematic data were processed in Visual 3-D™ Software (C-Motion, Inc.), where a specific upper limb model was created. Joint angles were expressed as Euler angle decompositions of the relative orientation of the distal segment relative to a proximal segment. The rotation order chosen (X–Y–Z) was kept in accordance with the ISB recommendations [22], but with the x-axis pointing from left to right, y-axis pointing forward, and the z-axis pointing upward. The expression "active range of motion" (AROM) was adopted to express the difference between the maximum and the minimum of the angle over the movement and the average of all subjects was considered for analysis. Movements assessed were expressed as shoulder flexion/extension (SFE), shoulder abduction/adduction (SAA), shoulder internal/external rotation (SIER), elbow flexion/extension (EFE), elbow pronation/supination (EPS), wrist flexion/extension (WFE) and wrist ulnar/radial deviation (WURD).

EMG data were processed in Matlab™ (Mathworks, USA), where a fourth-order Butterworth band-pass filter from 10 to 500 Hz was applied. To obtain the linear envelopes, data were