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EXPERIMENTAL EVALUATION OF THE EFFECT OF SHOULDER POSITION ON FOREARM PRONATION AND SUPINATION

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Abstract: *The aim of this article is to present experimental measurements of the highest rotational angle while pronating and supinating. Five healthy subjects underwent a kinematic study to investigate how shoulder position affects total elbow-wrist pronation and supination movement. The elbow-wrist's largest rotational angle for a complete cycle of pronation-supination was measured and recorded for 8 angles: 0 deg, 30 deg, 45 deg, 60 deg, 90 deg, 120 deg, 150 deg, 180 deg. The Biometrics Ltd data acquisition and processing system was used to acquire and process data in real-time from two Q150 single-axis torsiometer sensors at the same time. These measurements can be greatly beneficial for understanding the role of forearm pronation/supination on upper limb injury mechanisms.*
Key words: *Elbow joint, wrist, shoulder, pronation, supination, Biometrics, torsiometers.*

1. INTRODUCTION

The significance of biomechanical assessments of human has increased over the past few years, thanks to the development of data acquisition and processing systems. There has been an increased demand to identify critical parameters and obtain data that define the optimal and unceasing traceability characteristics of human behavior modification, attributes that can assist in the diagnosis, treatment of chronic diseases, and aid in the recovery of human mobility [1-7]. The current expertise of measuring and collecting life data of the human locomotion system has been publicized by researchers in different scientific papers [8,9]. Measurement accuracy, consistency, and reliability of goniometer sensors have been compared with different methods and innumerable advantages exhibited and utilized in the development of medical robots or rehabilitation devices [10,11]. During manual activities, forearm pronation is prevalent and has been connected to upper limb disorders in an extensive population with Parkinson's disease, sclerosis disease, osteoarthritis, stroke, or occupational trauma [4, 12]. One of the most common types of disability after stroke is restriction of physical abilities, weakness or paralysis of members on one side of the body, difficulty gripping or holding things, and a slowed ability to communicate, facts that evince the significance and strengthen the biomechanical development research [13]. One of the important movements to be trained on stroke patients during rehabilitation exercises is forearm pronation and supination as this movement is critical for activities of daily living (ADL's) [7,14]. Pronation and supination involve rotation of the radius over the ulna around the forearm's longitudinal axis. Disorders in the elbow joint, hand joint, and forearm bones can restrict this movement [15]. This movement can be fast, reaching higher angular velocities than wrist flexion/extension or radial/ulnar deviation; thus, it can be difficult to measure. Despite this fact, forearm pronation and supination biomechanical data are needed for a variety of daily activities [14] to understand the postural demands of the forearm. Five

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healthy subjects were evaluated, and a kinematic test was performed to examine the effect of the shoulder position on the total elbow-wrist pronation and supination movement [12-19]. To ensure consistency, accuracy, and quality results, subjects were instructed to perform tasks based on an experimental protocol. The subjects became accustomed to the tests by repeating them several times before starting the final experimental test.

2. EXPERIMENTAL PROTOCOL

2.1. Equipment

Biomechanical data is collected in this study by using Biometrics LTD system [20], which includes instruments like wearable devices, electrogoniometers, torsiometers, contact switches, and EMG sensors. Biometrics system is an increasingly used equipment in biomechanical research [2-9, 15] medical robotics and rehabilitation [21-23]. The sensors are attached across the joint employing double-sided medical adhesive tape and connected to the range of Biometrics' measuring devices. The sensors and measuring devices are portable, lightweight and unobtrusive, allowing data on human activity to be displayed or recorded without interfering the subject's movements in the normal environment.

Their main sensor characteristics are accuracy: ±2º for a measured interval of at least 90º, repeatability: 1º for a measurement interval of at least 90º, measuring temperature range: from 10ºC to 40ºC.

Fig. 2 depicts a block diagram of the data acquisition process. The equipment (Fig.1), used for data acquisition was the MWX8 Data LOG device (129 grams) which works within the Biometrics LTD data acquisition system [20], commonly used software in scientific research on human biomechanical evaluations [5-10]. The acquisition unit allows the collection of both analog and digital data, from a maximum number of 24 sensors simultaneously with frequencies up to 20 kHz. By using Bluetooth® technology, the MWX8 device captures and computes measurement data from both torsiometers T1 and T2, which is then transferred to a PC [20].

Fig. 1. a) The wearable device MWX8 Data LOG; b) Biometrics "Q" series, single axis torsiometers

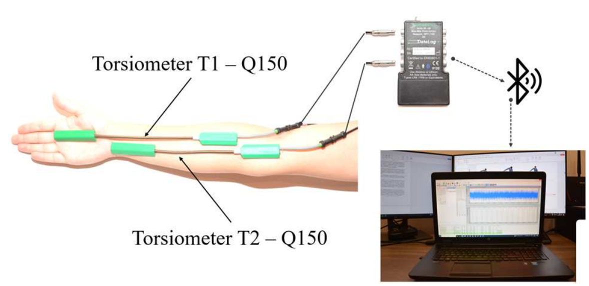


Fig. 2. The block schema of the data acquisition process.

2.2. Sample of subjects

For this study, a homogeneous group of five healthy subjects who did not have any conditions or history of diseases of the upper limbs were chosen and gave their written consent to take part in the experimental tests. The anthropometric representative data of the participants in the experimental tests of elbow and wrist joints are comprised in Table 1, where L1 - arm length, L2 - forearm length and L3 - palm length (Fig.3).

Table 1.

Anthropometric subjects' data

Subject	Gender	Age	Weight	Height	L1	L2	L3
		yrs	kg	cm	cm	cm	cm
S1	M	42	96	180	23	25	18
S2	F	41	53	160	24	24	18
S3	M	36	83	181	23	25	17
S4	M	35	99	180	30	27	18
S5	M	42	65	160	25	24	17

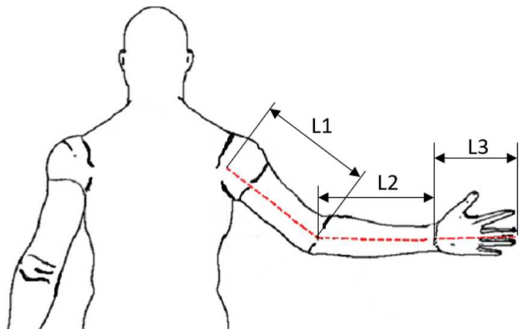


Fig. 3. Anthropometric parameters.

2.3. Experimental tests

The total pronation-supination of the elbow (T1) and the partial pronation-supination of the wrists (T2) were measured independently by using two torsiometers, portable sensors, and their chosen position can be seen in Fig. 4. a) pronation, b) neutral position, c) supination.

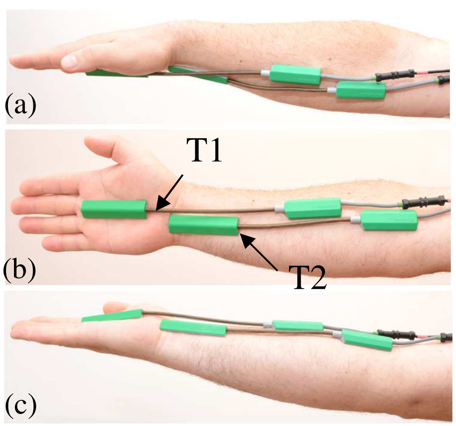


Fig. 4. Anatomical sensor position on the longitudinal axis of the humerus, a) Pronation, b) Neutral, (c) Supination.

The study success hinged on its ability to accurately quantify the set of positions, number of repetitions, and time duration needed for a complete pronation-supination cycle (Fig.7). To ensure consistent measurement outcomes and provide guidelines for subjects being assessed, a protocol measurement was created. To gauge elbow-wrist pronation and supination, every subject repeats the motion for 15 consecutive cycles to overcome biological variability factors. The recorded number of cycles was 600, and each cycle was performed at a steady pace for a time span of between 0-10 seconds. The largest rotational angle of the elbow-wrist for a complete cycle of pronation-supination was measured for eight shoulder positions (Fig.5), the subjects execute in total forty tests as ruled by protocol measurement, exemplified in Fig.6 for 90-deg shoulder position:

- Sequence 1: arm positioned frontal in fully extension condition, with palm in neutral position (Fig.6. a)
- Sequence 2: turn the palm counterclockwise on its longitudinal Z-axis arm to the highest tolerable pronation angle, then bring it back to neutral position (Fig.6. b).
- Sequence 3: turn the palm clockwise on its longitudinal Z-axis arm to the highest tolerable supination angle bring it back to neutral position (Fig.6. c).

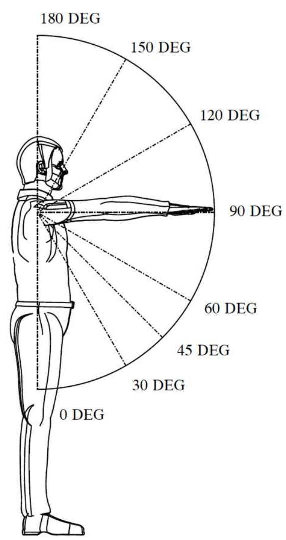


Fig. 5. Protocol measurement positions.

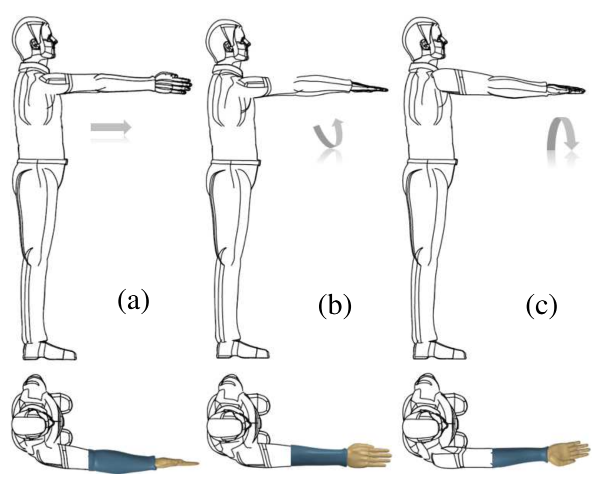


Fig. 6. Shoulder and palm position at 90-deg angle: (a) Neutral (b) Pronation (c) Supination.

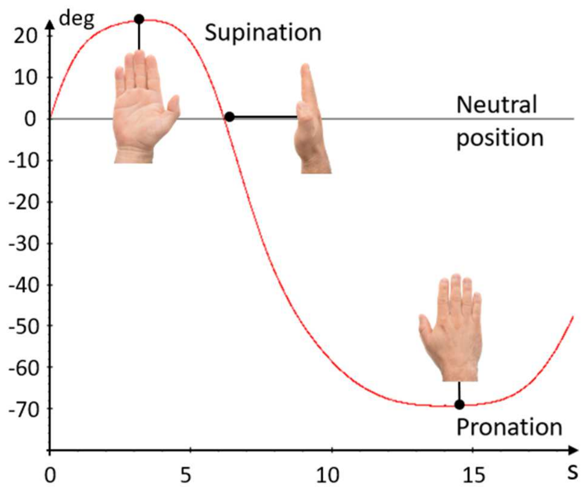
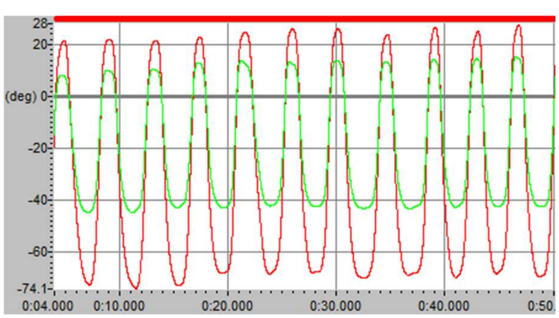


Fig. 7. Definition and result of a complete pronation-supination cycle (sequence 1-3).

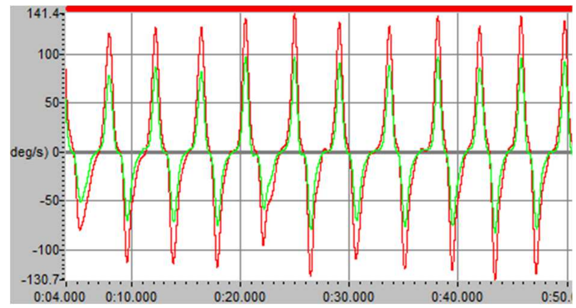
3. RESULTS

The results were obtained and studied using Biometrics LTD analysis software. The quantification of hand and forearm motions is important, because it can help identify potentially injurious hand/wrist and forearm range of motions. Also, the current kinematics protocol aims to assess the impacts of movement characteristics (velocity, angular variation), which consist of exposure to various shoulder positions, repetitive stress cycles, and the total amount of time spent.

Tables 2-5 compile a summary of the largest pronation-supination angle collected across all forty tests. The amplitudes of pronation–supination angle [deg] and velocity [deg/s] were obtained for each test as data files. The Biometrics software system collected and processed a sequence of consecutive cycles for all experimental data, an example of variation in movement for subject S1, relative to time [s] are shown in the next graphs for different positions:

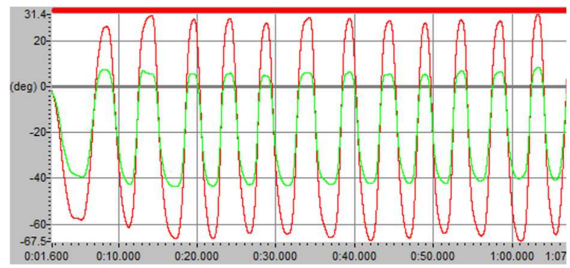


(a)

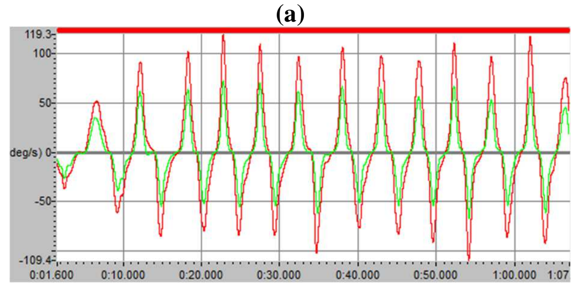


(b)

Fig. 8. Consecutive cycles of elbow joints movements at 0-deg position, T1 - red line, T2 – green line: a) angular variation [deg], b) velocity [deg/s].

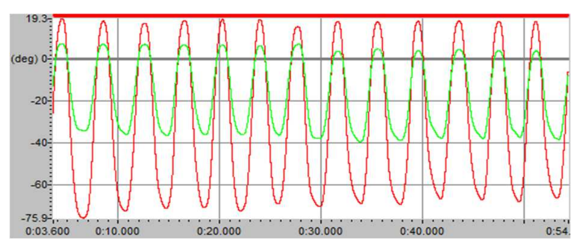


(a)

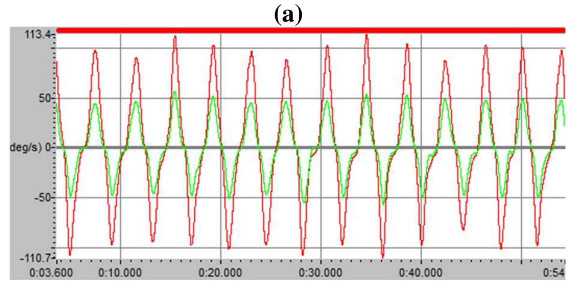


(b)

Fig. 9. Consecutive cycles of elbow joints movements at 90-deg position, T1 - red line, T2 – green line: a) angular variation [deg]; b) velocity [deg/s].



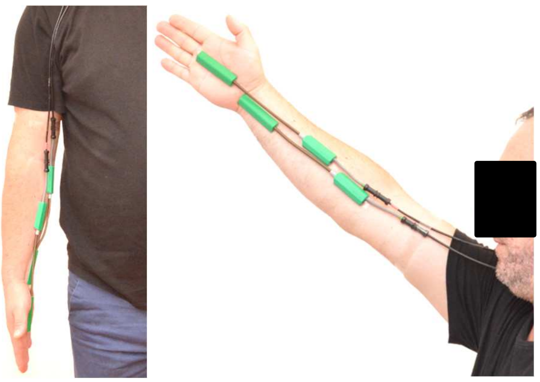
(a)



(b)

Fig. 10. Consecutive cycles of elbow joints movements at 150-deg position, T1 - red line, T2 – green line: a) angular variation [deg], b) velocity [deg/s].

Fig. 11 depicts a participant configuration setup during the experiment, with images of him standing with his shoulder tilted at 0 degrees and 150 degrees, and two torsiometer sensors placed on the longitudinal arm axis.



(a) (b)

Fig. 11. Configuration setup with 2xQ150 Biometrics sensors. a) 0-deg position, b) 150-deg position.

The collected experimental data files were imported into the SimiMotion program [24] with the help of which the average normalized pronation-supination cycles corresponding to each imported data file were obtained. Fig.12 illustrate a normal cyclic file imported in SimiMotion for phase processing. After obtaining the average cycle diagrams of all tests, a series of comparisons were made to analyze the influence of shoulder position to pronation-supination angle of the elbow and wrist joint. The measurement's performance is assessed by calculating the standard deviation (StdDev), which displays the difference between the nominal cycle values and the average value. In Fig. 13, a), b), and c), plots of mean cycles and their comparison with mean cycle + StdDev and mean cycle – StdDev of the subject S1 are shown.

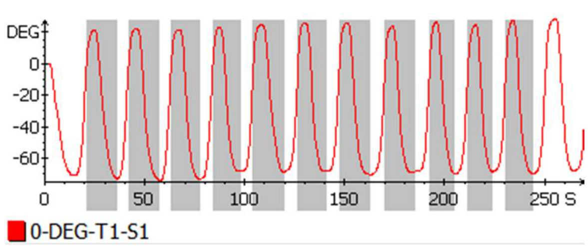
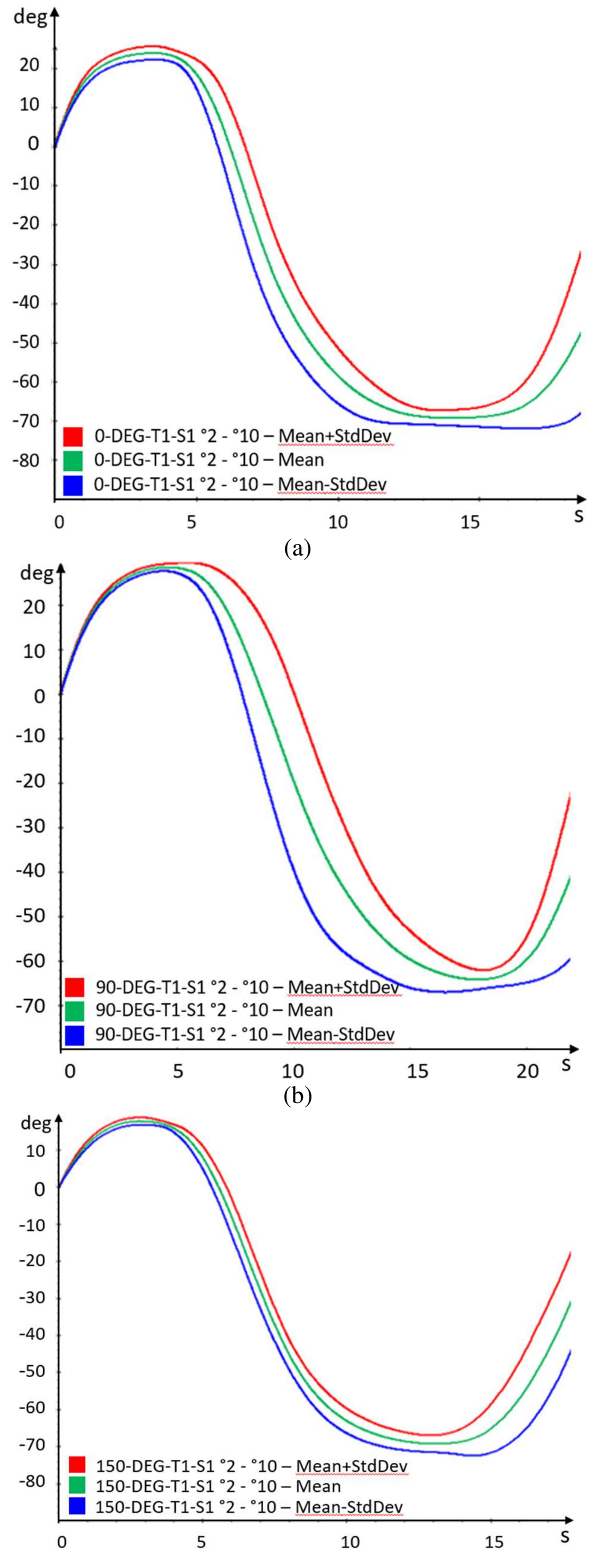


Fig. 12. Biometric cycles imported in SimiMotion for phase processing (exemplified for S1: 0-deg)



(c)

Fig. 13. Mean cycle, mean cycle + StdDev, mean cycle – StdDev for pronation-supination for experiment test **S1**, at position: a) 0-deg, (b) 90-deg, c) 150-deg.

Table 2.

The maximum elbow supination angle [deg] for eight shoulder positions, recorded from T1, (Fig. 4).

Shoulder Position	ELBOW - SUPINATION – [T1]				
	S1	S2	S3	S4	S5
0 deg	28.8	41.4	39.8	51.9	31.5
30 deg	29.3	33.4	56.4	35.1	29.7
45 deg	31.4	39.2	50.1	40.6	25.2
60 deg	30.3	30.3	38.4	32.0	23.7
90 deg	32.4	39.2	43.0	36.2	22.8
120 deg	28.5	31.0	31.5	28.2	23.3
150 deg	20.2	24.6	36.5	22.2	25.2
180 deg	20.8	17.0	27.3	18.8	20.2

Table 3.

The maximum wrist supination angle [deg] for eight shoulder positions, recorded from T2, (Fig. 4).

Shoulder Position	WRIST - SUPINATION – [T2]				
	S1	S2	S3	S4	S5
0 deg	16.4	32	30.2	23	28.3
30 deg	12.1	30.2	30.4	25.2	16
45 deg	12.5	39.1	23.7	30.1	21.2
60 deg	13.5	13.5	17	23.6	13.4
90 deg	8.6	37.3	20.2	19.5	17.6
120 deg	12.1	32.4	16.4	19.4	16.1
150 deg	7.6	20.2	16.7	13.6	11.4
180 deg	9	16.2	11.8	14	14.5

Table 2 and Table 3 indicates that the elbow joint's maximum **supination angle** ranged from 17° and 56.4°, while the wrist joint's maximum angle ranged from 7.6° and 39.1°. Table 4 and Table 5 indicates that the elbow joint's maximum **pronation angle** ranged from 48.5° and 97°, while the wrist joint's maximum angle ranged from 44.5° and 65.1°.

Table 4.

The maximum elbow pronation angle [deg] for eight shoulder positions, recorded from T1, (Fig. 4).

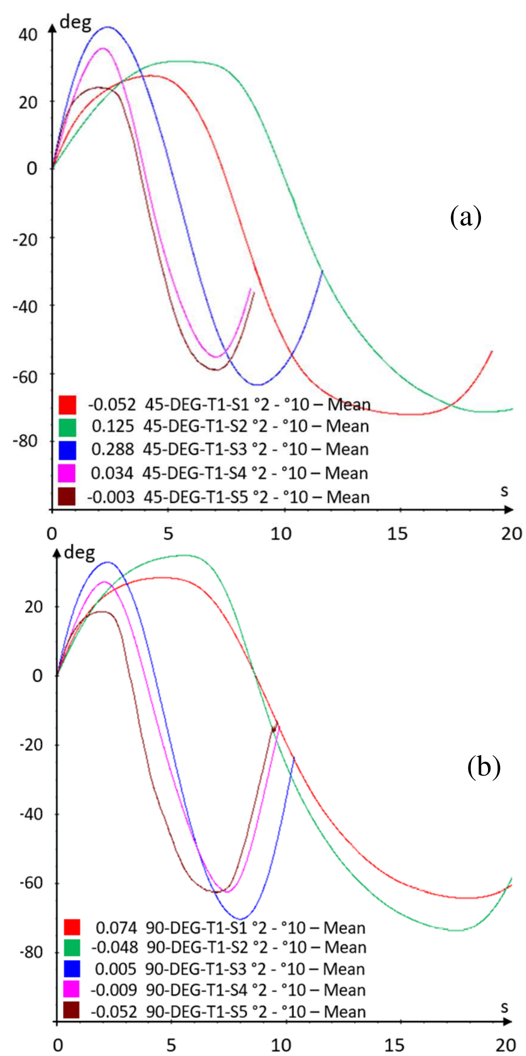
Shoulder Position	ELBOW PRONATION – [T1]				
	S1	S2	S3	S4	S5
0 deg	-74.7	-66.3	-71.1	-67.8	-48.5
30 deg	-77.9	-84.5	-62.5	-70.2	-53.4
45 deg	-76.8	-79.6	-68.8	-63.0	-61.2
60 deg	-70.3	-70.3	-79.2	-64.9	-64.3
90 deg	-67.8	-78.7	-76.1	-71.0	-65.1
120 deg	-72.0	-85.8	-82.9	-71.5	-63.0
150 deg	-76.3	-90.8	-81.8	-84.6	-61.2
180 deg	-78.7	-88.3	-97.0	-88.4	-69.3

Table 5.

The maximum wrist pronation angle [deg] for eight shoulder positions, recorded from T2. (Fig. 4).

Shoulder Position	WRIST PRONATION – [T2]				
	S1	S2	S3	S4	S5
0 deg	-45.5	-51.3	-40.0	-46.0	-39.8
30 deg	-48.2	-58.8	-34.9	-46.2	-42.4
45 deg	-42.7	-55.8	-37.4	-38.0	-36.3
60 deg	-41.1	-41.1	-44.9	-42.4	-43.2
90 deg	-44.1	-59.3	-40.7	-45.9	-38.7
120 deg	-36.1	-57.6	-43.6	-45.0	-37.5
150 deg	-39.8	-65.1	-44.0	-52.9	-44.5
180 deg	-37.8	-64.9	-51.1	-52.2	-37.6

The following combined diagrams display the mean cycles obtained by all subjects during the experimental measurements of pronation-supination, Fig. 14 a), b), c).



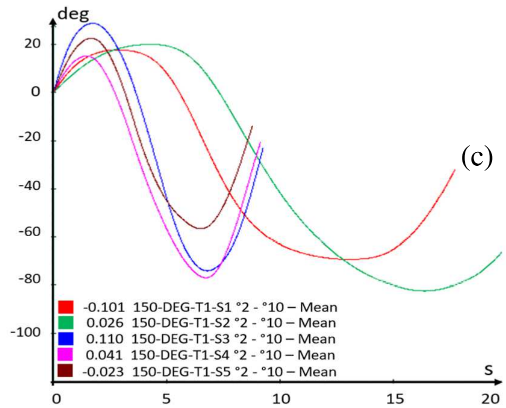


Fig. 14. Diagrams of mean cycle for all subjects recorded by T1 at: a) 45-deg, b) 90-deg, c) 150-deg.

5. DISCUSSIONS

The purpose of this study was to examine and record the angle and speed of various shoulder positions during maximum permitted pronation and supination movements in five healthy subjects. Its unique contribution lies in considering the effect of shoulder posture on biomechanical changes of the elbow-wrist independently. Although forearm pronation and supination are frequently associated with manual tasks and have previously been associated with injury, their role in injury development has not been explored. The goal of these measurements is to translate this knowledge into a model for rehabilitation. The acquisition process of movement for pronation and supination requires the torsiometers to be positioned correctly, and during experiment challenges have been identified throughout the process. The advantages of electro-goniometry are that it is noninvasive, it is well accepted by the participants in experimental tests and no dangerous effects on the human body are registered [1–6]. T1 and T2 reveal about a 32° difference between the total elbow pronation values and the partial wrist **pronation** values, with a similarity for **supination** of about 17.3°.

For future work, an increased number of subjects will be considered for the biomechanical evaluation as well as a deeper investigation of the effect of elbow and shoulder position on the ADL for different ROM's.

6. CONCLUSIONS

In this study, the influences of elbow-wrist pronation-supination on the variation of eight flexion angle positions of the human shoulder during forty performed tests from the data of five healthy subjects were concluded by the level of largest angular amplitude. When shoulder flexion increases towards maximum of 180 deg, both sensor measurements display an equivalent pattern while the pronation angle reaching its maximum value the supination caused the opposite effect, angle decreasing for both the elbow-wrist joints.

Conflict of interests: There is no conflict of interests connected to this article.

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Evaluarea experimentală a efectului poziției umărului asupra pronației și supinației antebrațului

Scopul acestui articol este de a prezenta măsurători experimentale ale unghiului maxim de rotație în timpul pronației și supinației. Cinci subiecți sănătoși au fost supuși unui studiu cinematic pentru a investiga modul în care poziția umărului afectează mișcarea totală de pronație și supinație pentru cot și încheietura mâinii. Unghiul maxim de rotație al cotului-încheietura mâinii pentru un ciclu complet de pronație-supinație a fost măsurat pentru 8 poziții. Aceste măsurători pot fi benefice pentru înțelegerea rolului pronației/supinației antebrațului asupra mecanismelor de leziune al membrelor superioare. Rezultatele au fost obținute cu instrumente din cadrul Biometrics LTD și procesate cu ajutorul SimiMotion.

Cuvinte cheie: Articulația cotului, încheietura mâinii, umărului, pronația, supinația, biometria, torsiometre.

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