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KINESIOLOGY INVESTIGATION OF ELBOW FLEXION POSTURES USING HUMAN DIGITAL MODELLING SIMULATION FOR POTENTIAL ENERGY AND MUSCLES ACTIVITY

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Abstract

Kinesiology studies that address the mechanics of human body movements are not widely carried out especially for the Malaysian population. Kinesiology investigation was conducted on various working postures for the possible range of motions of elbow flexion. Posture is defined as dynamic balance movement involving the contractions of antagonistic pair muscles. The result from health science studies was referred in identifying the agonist and antagonist muscles that correspond for the elbow flexion movements. Human digital modelling software has been used to simulate various elbow flexion postures within the range of motion to find the potential energy and muscles activity changes regarding kinematic deviations. The human model was developed according to published Malaysian population anthropometry data. The model was simulated to hold elbow flexion postures in a normal standing position with gravity acceleration for the 30-minutes duration. This study's finding expressively provides quantitative appendices for ergonomist to distinguish the risk of elbow flexion postures.

Keywords: Elbow flexion, Malaysian population, Muscles activity, Potential energy, Simulation.

1. Introduction

Kinesiology is the scientific study of human or non-human body movement. Kinesiology addresses the physiological, biomechanical, and psychological mechanisms of a person's body. Applications of kinesiology to human health include biomechanics and orthopedics (conditions involving the musculoskeletal system). A case study regarding elbow flexion working postures has been studied stated that poor working conditions of elbow flexion postures and musculoskeletal problems in Iranian handwoven carpet industry occurred in high rate [1]. The study involved two phases where the first phase, work musculoskeletal disorders (WMSDs) symptoms in 9 Iranian provinces were surveyed by questionnaire among 1439 randomly selected weavers. Working posture and weaving workstations were ergonomically assessed as well. The results revealed that symptoms from the musculoskeletal system occurred in high rate among weavers with the prevalence significantly higher than that of the general Iranian population ($P < 0.001$). This case expresses the significance of detail postures study in evaluating elbow flexion diversity.

In 1993, McAtamney had developed a rapid upper limb assessment (RULA) tool which assesses WMSDs by allocating risk scores on various postures, loads and repetitions which covers body sections of the upper arm, lower arm, wrist, neck, trunk and leg. The scores were based on a compilation of previous studies and experiments as mentioned in the paper published [2]. Working static postures, known as dynamic balance movement require contractions of both agonist and antagonist muscles also known as antagonistic pair muscles [3]. Narrowing the investigation to various elbow postures inflict on how much these postures differentiates in term of corresponding (antagonistic pair) muscles activity and kinematic potential energy. RULA has divided elbow flexion postures into 2 scoring interpreted from [4] reference book. Human potential energy is the energy difference between the energy of an object in a given position and its energy at a reference position [5] in another word, the energy required to hold the postures against the force of gravity or any external forces. Figure 1 shows a variation of elbow working postures which give indicate different risk of WMSDs in RULA [2].

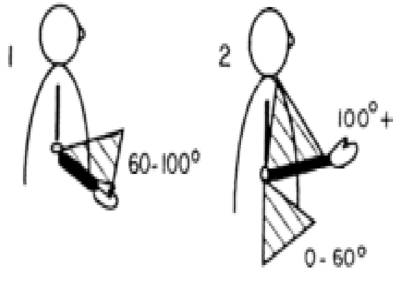

Fig. 1. Elbow flexion postures variation in RULA.

2. Muscles and Movements

Human movements are generated by activities of the human body's muscles. Different types of movements or postures will necessitate diverse muscles activity. Diversity in muscles activity gives a variety of WMSDs potential risk. Muscles are the only tissue in the body that has the capability to contract thus move the other parts of the body. Human muscles are classified into 2 types of contraction which are voluntary and involuntary. Involuntary muscles include cardiac (human heart) and smooth (wall of human organs) muscles. Voluntary muscles are the skeletal muscles that produce body movements have been classified into 4 functional groups as listed below [6].

- Agonist - provide major force for producing specific movement.
- Antagonist - regulate the agonist by contracting.
- Synergist - assisting prime mover (agonist or antagonist) by adding extra force and reduce undesirable movement as prime mover contract. Sometimes referred as neutralizers.
- Fixators - synergists that immobilize a bone or muscles origin.

3.2. Muscles contraction activity

Muscles contraction is the activation of tension-producing spots within muscle fibers. Muscle contractions can be described based on two variables which are length and tension. Muscle tension is the force exerted by the muscle on an object. There are generally 2 types of muscles contraction, first is muscle contraction described as isometric when muscle tension changes without any conforming changes in muscle length and muscle contraction described as isotonic when the muscle length changes while muscle tension remains the same [7, 8]. Associate dynamic balance movement and isometric contractions give the postures as an isometric muscles contraction which specifies for co-contraction between agonist and antagonist muscles [8, 9]. Muscles activity practically has been measured using electromyography (EMG) device that returns the alternate voltage signal (mV) measurement of the muscles and represented by muscle maximum voluntary contraction (MVC) percentile. 30% MVC identified as a hard level of muscles contraction where the muscles strain will occur within and above the MVC percentage [10].

3.3. Prime mover muscles identification

Prime mover or agonist's muscle depends on the direction of movements (interchangeability per the direction or major contraction). For elbow flexion postures, which defined as dynamic balance movement where both agonist and antagonist muscles will have contractions or activity to hold required static postures positioning. Corresponding muscles for elbow flexion has been referred to Elsevier journals compilation 9th edition [11]. This identification process is purposely to measure the stress on the corresponding muscles providing major force for the movement to occur. Table 1 shows the corresponding muscles (antagonistic pair) of elbow flexion.

3.4. Muscles range of motion

Awkward postures associated with a range of motion (ROM) defined as joint rotations near the end of the range. Risk of overexertion injury also increased near the end of the range. Different postures practiced within ROM give different kinematic positioning and yet require different potential energy and muscles contraction activity. Table 1 shows the ROM of elbow flexion as evaluated by the Department of Social Health Services, Washington [12].

Table 1. Elbow flexion agonist, antagonist and range of motion.

Movement	ROM (degree, °)	Muscles Type	Muscles [7]
Elbow flexion	0 - 150	Agonist	Biceps Brachii Brachialis Brachioradialis
		Antagonist	Triceps brachii

3. Investigation Methodology

The human digital modelling simulation has been conducted using AnyBody Technology software named AnyBody Modelling System (AMS). This software run the analysis of full body musculoskeletal system of required activities for both dynamic and static. The capability and validity of the software have been tested and published in 2007 by Shin et al. [13]. Software’s study simulation processes included anthropometric data changes and the time window sampling envelope.

3.1. Model scaling

AnyBody Managed Model Repository (AMMR) provide standard models that can be adapted to user or researcher needs. The standing model in AMMR represents the 50th percentile of the United State of America male which can be modified to fit Malaysian anthropometric measurement. In this study, the mean mass (67.35 kg) and height (172.02 cm) of males age 18-24 based on [14] were used to develop the Malaysian mannequin. The software automatically scales the length and mass of the segment based on uniform scaling law as published by Winter [15].

3.2. Simulation setup

The simulation was carried out with research scopes and constraints including static postures practices of elbow flexion from 0° to the maximum ROM of 150° with 15° increment for straight 30-minutes in each posture. Another joint of glenohumeral was set up as the default of standing position shown in Table 2. Figure 2 shows the human digital modelling used for the analysis.

Table 2. Elbow flexion agonist, antagonist and range of motion.

Joint Posture	Degree (°)
Glenohumeral flexion	0
Glenohumeral abduction	10

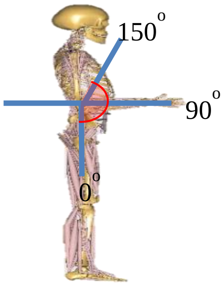

Fig. 2. Simulation model with Malaysian population anthropometry.

The potential energy, antagonistic pair muscles activity and maximum muscle activity were collected over a 5-minute interval of time window sampling. Statistical hypothesis test has been conducted on maximum muscles activity and potential energy to find the significance of scattered data to develop a mathematical model. The scattered data tested with the regression analysis to find the P-value compared with the significant level of 0.05 [16]. The P-value analyzed should be less than 0.05 to indicate less than 5% of the data occurs by chance or random.

4. Result and Discussion

The average value for the 30-minutes duration was calculated for kinematic potential energy, antagonistic pair muscles activity and the maximum muscle activity. The results show the relationship between those parameters across elbow flexion angles were plotted.

4.1. Kinematic potential energy

The potential energy data of tested postures measured was presented in calories. The scattered data plotted showed a cubic polynomial trend from 2 turning points observes as determined in algebra studies field. Figure 3 shows the plotted result with trend line and regression included. This relationship shows the energy required to hold the posture per kinematic displacement of mass and location from the original location affected by gravity downward acceleration. Regression analysis was done on the scattered data along tested ROM give the P-value of 4.50853E-10. This gives the low possibility of the data befalls by chance and can be proceeded to mathematical model development.

The distribution of kinematic potential energy across the elbow flexion angles have projected a cubic polynomial trend. This trend-line indirectly shows how the elbow flexion angles will require different energy consumption. Energy consumption is one of the parameters in determining muscles capacity or fatigue. Using regression calculation in finding the best fit data, the trend line equation has been generated as shown in Eq. (1) with y as the kinematic potential energy and x as the elbow flexion angles.

$$y = -4E\text{-}06x^3 + 0.001x^2 + 0.007x + 625.71 \tag{1}$$

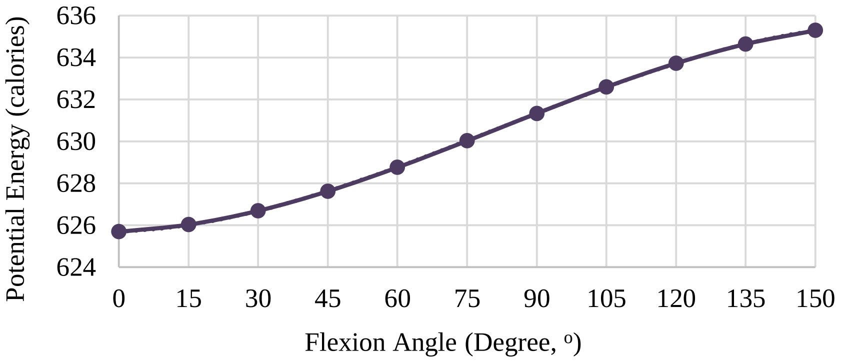

Fig. 3. Potential energy across elbow flexion angles.

4.2. Muscles activity

Antagonistic pair muscle consists of both types of muscles corresponds for the postures or dynamic balance movement to occurs. Muscle activity presented in the percentile of MVC value of each individual muscles. Other parameter maximum muscles activity used to indicate overall activity by comparing all the muscles contraction activity in the body within the time window and result in the highest MVC.

Co-contraction between antagonistic pair muscles has been identified across the flexion angles changes. This rhythm makes a subjective relation between corresponding muscles where other muscles may also have high contraction activity in term of MVC for the postures occurrence. Figure 4 shows the antagonistic pair muscles activity over elbow flexion angles. Figure 5 shows the maximum muscle activity of the overall body. Regression analysis for maximum muscles activity gives the P-value of 0.286162706. This value is larger than 0.05 which accept the null hypothesis of no relationship between tested variables flexion angles and maximum muscles activity.

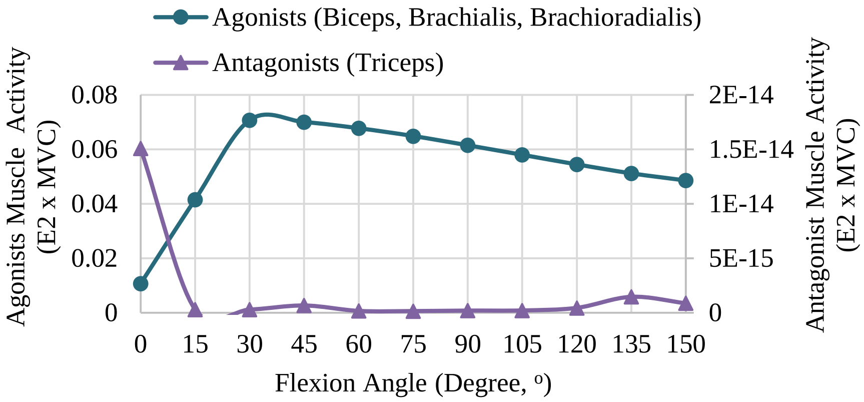

Fig. 4. Elbow flexion antagonistic pair muscles activity.

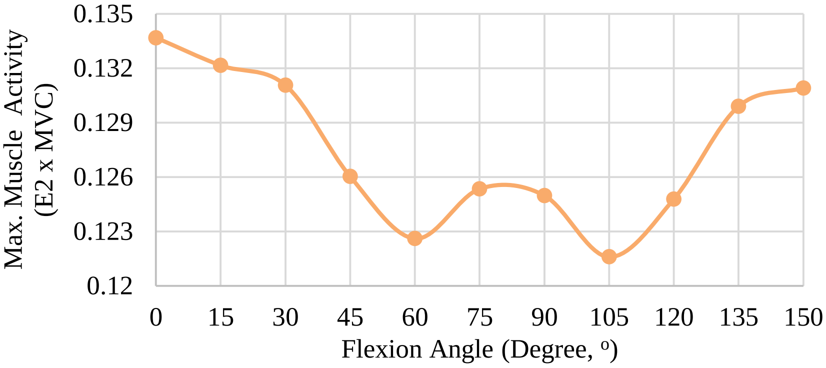

Fig. 5. Elbow flexion maximum muscles activity.

Figure 5 seen as a potential parameter of maximum muscle activity indicates the highest muscle activity for the overall human body in specific time which can be distributed into classes as low (<33.3%), medium (>33.3% and <66.7%) and high (>66.7%). Table 3 shows the elbow flexion angle index mapping of maximum muscles activity (MMA).

Table 3. Elbow flexion angles MMA index mapping.

Elbow Flexion Angles (°)	Low (0 - 33.3%)	Medium (33.4 - 66.7%)	High (66.8 - 100%)
0 - 30			✓
31 - 45		✓	
46 - 120	✓		
121 - 150			✓

5. Conclusion

Quantitative parameters as potential energy and MMA result has founded to be a prospective parameter in assessing the risk of WMSDs. This relationship offers an estimation of how the flexion angle of elbow joint energy requirement and stress which will add a definite fact for ergonomist to control the workstation or tasks activities. However, this study was limited to the model generated by the AMS software is only based on the average Malaysian population height and mass for certain ages with only emphasized on upper limb postures diversions only for the simulation. This scopes and results prompt for a full study of working postures differences in quantitative kinesiology outputs.

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Abbreviations

AMS	AnyBody Modelling System
AMMR	AnyBody Managed Model Repository
EMG	Electromyography
MMA	Maximum Muscles Activity
MVC	Maximum Voluntary Contraction
ROM	Range of Motion
RULA	Rapid Upper Limb Assessment
WMSDs	Work Musculoskeletal Disorders

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