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LINEAR REGRESSION MODELS OF THE 3D SCAPULO-HUMERAL RHYTHM FOR ACTIVE/PASSIVE AND STATIC/DYNAMIC CONDITIONS.

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SUMMARY
To estimate the clavicle and scapula orientations based on the humerus' position with respect to the thorax, linear regression models of the scapulo-humeral rhythm were developed. Since previous regressions were based on static positions, new specific equations were established for static positions and dynamic motions in active and passive states. Ten asymptomatic subjects were setup with reflective markers on the trunk and upper limb. Dynamic motions and static positions in active and passive conditions were recorded respectively using an optoelectronic system. The equations for the four conditions show considerable differences which justify the use of the respective equations to estimate scapulo-humeral rhythm according to the type of motion performed.

INTRODUCTION
The scapulo-humeral rhythm consists of the interaction between the sterno-clavicular (SC), acromio-clavicular and gleno-humeral joints [1]. To describe this relation for each shoulder joint, De Groot and Brand [1] established multiple linear regression equations to estimate joint rotations according to the arm position. However, the measures were based on many static positions while exerting a 20 N abduction or adduction force. The application of the previous equations for simulation purposes [2, 3] often does not correspond to the condition in which the data were acquired. Additionally, several studies reported shoulder kinematics differences according to motion type during active compared to passive [4] and dynamic compared to static [5, 6].

Thus, the intent was to describe multiple linear regression equations for the 3D scapulo-humeral rhythm in dynamic and static each in active and passive conditions.

METHODS
Ten asymptomatic subjects (gender: 5 males, 5 females; age: 25 ± 3 years; height: 1.73 ± 0.10 m; weight: 67.6 ± 10.6 kg) were setup with thirty-five reflective markers on the trunk and upper limb in accordance to Jackson et al. [8]. Markers were tracked by 18 Vicon™ cameras at 100 Hz.

The static condition consisted of maintaining consecutively 21 arm positions spread over 4 planes of elevation (0°, 30°, 60° and 90°) and 6 arm elevations (0° only recorded once, 30°, 60°, 90°, 120° and 150°) which were recorded for 5 s. The dynamic condition was performed at a controlled speed of 3 s to raise the arm to 150° and 3 s to descend the arm (~50°/s) imposed by a metronome. Arm elevations and depressions were executed at each 10° of plane of elevation from 0° to 90°. For the passive condition, the subject was instructed to completely relax his arm which was maintained in position or manipulated by a professional kinesiologist.

The anatomical coordinates system and the Euler or Cardan angles sequence was based on the International Society of Biomechanics (ISB) recommendations [7]. For each arm posture, scapular and clavicular orientations with respect to the trunk were described using the three SC rotations and three scapulo-thoracic (ST) rotations.

The six dependent factors fitted in separate models were the SC angles of retraction, elevation and axial rotation and the ST angles of protraction, lateral rotation and posterior tilt. Their average values were estimated by a function of the independent factors. Euler angles of the humerus with respect to the thorax and a constant term represented the independent factors. As developed by Grewal and Dickerson [9], thoraco-humeral (TH) axial rotation was included as an additional independent factor, although the protocol did not involve internal or external rotations. Personal factors such as anthropometrical dimensions, gender, age, weight and height were not included in the model since they previously showed insignificance [1, 9].

The independent factors were included in the model if they were statistically significant following a t-test. The combination of this best set of independent factors was tested by ANOVAs to determine if the resulting equation was statistically explaining the dependent variable. The significance level was set a priori to $\alpha = 0.05$. The proportion of the variance in the values of the dependent variables explained by all the independent variables was assessed with adjusted r^2 and an estimate of the error variance was provided with root mean square error (RMSE).

RESULTS AND DISCUSSION

The equations of linear regression for each dependent variable (Table 1) are composed of the addition of a constant term and the three coefficients multiplied by their respective independent variable (C + TH_y x TH plane of elevation + TH_z x TH elevation + $TH_{y'}$ x TH axial rotation). The equations of linear regression were significantly ($p < 0.0001$) explaining every dependent variable for all conditions according to the ANOVAs. Some constant terms and TH axial rotation parameters were excluded from the model as the t-test were non-significant. As expected the TH elevation is the most influent independent parameter for all conditions. The TH plane of elevation and TH axial rotation showed to be relatively important for the estimation of ST backward tilt during active conditions.

The observed RMSEs were comparable to a previous study [1]. While the adjusted r^2 values were generally near or over 0.1, the values for SC axial rotation were low as this rotation is particularly affected by soft tissue artefacts [10]. Due to this limitation SC axial rotation is often neglected in shoulder models [1, 10]. Values of the parameters for the different conditions show that ST lateral rotation contributes more to TH elevation of the humerus during the passive conditions. The TH axial rotation has more influence on ST backward tilt during the active conditions. For the dynamic conditions, TH elevation was a more important predictor of SC elevation.

CONCLUSION

New equations of linear regression were provided to represent specifically the dynamic, static, passive and active conditions. The coefficients for the three TH rotations were substantially different according to each condition. It is recommended to use the proper equations to describe the scapulo-humeral rhythm based on the type of shoulder motion of interest.

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Table 1: Linear regression parameters forming the equation and the corresponding adjusted r^2 and root mean square error (RMSE) for the four conditions.

	C	TH_y	TH_z	$TH_{y'}$	Adjusted r^2	RMSE (°)
DYNAMIC ACTIVE						
SC retraction	-3.114	-0.016	0.152	-0.013	0.55	6.48
SC elevation	1.952	0.011	0.109	0.006	0.38	7.01
SC axial rotation	-8.558	0.049	0.038	0.036	0.03	20.31
ST protraction	2.466	0.028	0.167	0.036	0.24	19.08
ST lateral rotation	2.237	-0.014	0.337	-0.021	0.54	14.47
ST backward tilt	-7.473	-0.073	0.131	-0.052	0.08	20.66
DYNAMIC PASSIVE						
SC retraction	-4.200	-0.006	0.142	-0.009	0.56	5.54
SC elevation	-2.840	0.018	0.163	0.002	0.59	5.97
SC axial rotation	-5.812	-0.013	-0.003		0.01	15.24
ST protraction		-0.019	0.182		0.09	29.74
ST lateral rotation	-4.697	0.025	0.429		0.58	16.02
ST backward tilt	-7.997	-0.019	0.182	-0.015	0.12	21.62
STATIC ACTIVE						
SC retraction	-0.847	-0.003	0.125	-0.006	0.36	5.76
SC elevation	0.741	0.014	0.061	0.013	0.08	8.50
SC axial rotation	-10.287	-0.033	0.048	-0.019	0.01	18.53
ST protraction	1.260	-0.020	0.196		0.09	25.62
ST lateral rotation	1.043	0.009	0.337	-0.011	0.33	16.21
ST backward tilt	-2.106	-0.053	0.091	-0.053	0.02	25.51
STATIC PASSIVE						
SC retraction	-4.357	0.004	0.166	-0.008	0.53	5.47
SC elevation		0.017	0.053	0.017	0.06	9.42
SC axial rotation	-6.696	-0.061	0.022	-0.032	0.04	14.06
ST protraction	3.336	-0.015	0.123		0.05	22.82
ST lateral rotation	-4.817	0.072	0.399	0.030	0.60	11.91
ST backward tilt	-7.199	-0.004	0.162	-0.024	0.06	22.54

Independent factors: C: constant term; TH_y: TH plane of elevation coefficient; TH_z: TH elevation coefficient; $TH_{y'}$: TH axial rotation coefficient (missing parameters indicate the non-significance and exclusion from the model)