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Musculo-tendinous stiffness of the head-neck segment for extension movement during application of quick-releases

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SUMMARY

Since head-neck segment stabilization is critical for human safety and balance control, the aim of this study was to investigate changes in musculo-tendinous stiffness of the head-neck segment during different tasks.

We propose to consider the head-neck segment as a single-joint system with a changeable geometry as proposed in [1]. The aim was to evaluate the musculo-tendinous stiffness for head extension movement. Based on kinematics and optimization procedure, different applications of quick-releases (QR) were performed at different % of Maximal Voluntary Contraction (MVC). Ten healthy subjects volunteered. A load cell instrumented by an electromagnet coupled with an Optotrak device was used to get input data for the model.

After QR, the musculo-tendinous stiffness (S) was evaluated as in [2]. Results showed a significant increase of S according to the external force intensity ($P<0.05$). The slope of the linear regression amounted to 3.16. This slope provides the stiffness index of the head–neck segment in extension. Comparisons with flexion results were performed.

INTRODUCTION

The head-neck stabilization is of great importance during human movement and balance control. The musculo-tendinous stiffness plays a major role to produce this stabilization. To date, extension movements have never been analysed.

The aim of this study was to evaluate the head-neck musculo-tendinous stiffness for extension during application of quick-release movements.

METHODS

Experimental design

Seven healthy subjects with no history of neck pain volunteered (31.7 ± 2.6 years). The procedures were similar as in [1]. The experimental device is presented in Figure 1. Briefly, subjects were seated on an adjustable seat and they wore a headgear with a linked to a wall-mounted system composed of a load cell (Eatons (Cleveland, USA) instrumented by an electromagnet (Mecalectros (Massy, France). Deactivation of the electromagnet triggered the release of the cable. Three-dimensional displacements of 6 light-emitting diodes (LEDs) positioned on the subjects were measured using the Optotrak Motion Capture System (Northern Digital Inc. Waterloo, Canada). Displacement signals of the LEDs were processed with respect to the shoulder reference point and low-pass filtered with a Butterworth filter (cut-off frequency: 20Hz; fourth order). All data were sampled at 200 Hz.

After warm-up exercises, twelve randomized QR trials were performed at force intensities between 20–70% MVC. Real-time force signals served as feedback, and were presented on a monitor in front of the subject.

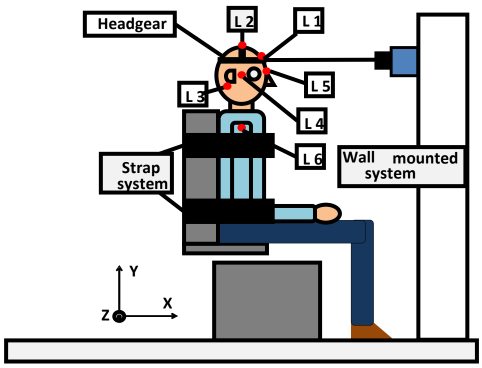

Figure 1: Subject placed in sitting. The head gear is fixed with a cable to the wall-mounted system. Kinematics of the five LEDs positioned on the head (L1, L2, L3, L4, and L5) was measured with respect to the LED6 (L6), placed on the shoulder.

Head-neck segment center of rotation calculation (CoR)

We used a validated model-based tracking process to determine the position of the head-neck *CoR* during QR perturbation. Details including software specifications and computational algorithms are in [1].

Calculation of static torque at the head-neck segment (T)

T was calculated as the product of the external force applied at the force sensor with the estimated lever arm, which is the vertical projection of the segment relating LED1 and the

CoR according as the estimated angle between the radius CoR - LED1 and the X axis.

Calculation of musculo-tendinous stiffness (*S*)

S was evaluated at time t = 30 ms, as the change in torque versus change in angle by considering the formula given in [2]:

$$S = \frac{\Delta T}{\Delta \theta} = \frac{\Delta \ddot{\theta} \times I}{\Delta \theta}$$

where $\Delta\theta = \hat{\theta}(t = 30ms)$, and $\Delta\ddot{\theta} = \hat{\ddot{\theta}}(t = 30ms) - \hat{\ddot{\theta}}(t = 0)$. I, T and $\hat{\ddot{\theta}}$ were computed from [1].

Statistical analysis

Means ± standard deviations of each normalized parameter were computed across all subjects' trials.

The slope of the linear regression between *S* and *T*, for all subjects combined, was established as a stiffness index.

RESULTS AND DISCUSSION

This study aimed to characterize the multi-linked head–neck segment musculo-tendinous stiffness through the application of QR method during extension movement.

Position of the center of rotation CoR

Mean values ranged from 300 mm to 420 mm. They averaged to 350 ± 40 mm for all the subjects. These values showed that the center of rotation location is similar from flexion to extension movements. Results indicate that *CoR* location did not change significantly during QR movement. This means that anthropometric characteristics as inertia remain constant during the experiment. Similar results were observed for the flexion movement [1].

Musculo-tendinous stiffness

Values for *S* ranged from 31.36 Nm.rad^{-1} to 487.21 Nm.rad^{-1} for all the trials and averaged to 215.86 ± 89.19 Nm.rad^{-1}. Fig.2 shows the linear regression between *S* and *T*. It can be seen that there was a positive association between the stiffness and the muscle torque (R^2=0.37; $P<0.05$). The slope between *S* and *T* amounted to 3.16 rad^{-1}. In flexion this slope is equal to 3.35 rad^{-1}.

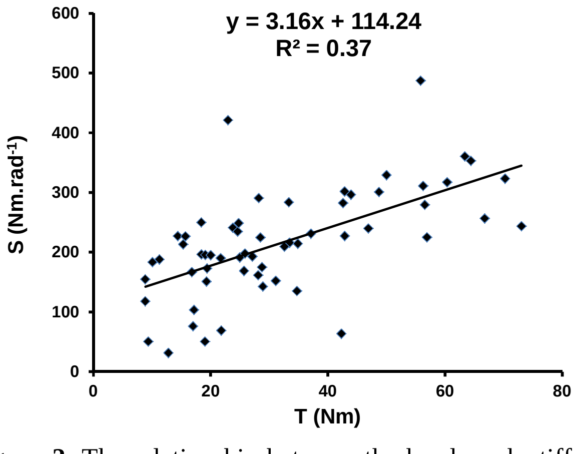

Figure 2: The relationship between the head–neck stiffness (*S*) and the isometric cervical extension torque (*T*) developed before the QR for all subjects. Linear regression showed a significant increase of *S* according to *T* ($P<0.05$).

We concluded that head–neck musculo-tendinous stiffness increases with the torque developed by cervical muscles in extension. In addition, since there were no change in the inertia values and position of *CoR* with the exertion level, the increase of musculo-tendinous stiffness observed here should not be due to any geometrical changes, but rather is due to the increase in the number of actin–myosin cross bridges generated by enhancement of activation level. Concordant conclusions were reached for the flexion movement [1].

Values for *S* observed in extension are higher than those observed for flexion (i.e. from 28.38 Nm.rad^{-1} to 216.28 Nm.rad^{-1} in flexion). These significant differences were in contrast to the similar global neck stiffness computed by other authors in flexion and extension [3]. However, discrepancies in the experimental requirements (a dropping mass attached to the head and the required external force intensities) may be responsible for these differences. The aforementioned references introduced a damping component in their analysis, while the QR method excludes damping. Current stiffness results agreed well with the fact that the physiological cross sectional areas for the extensor muscles are superior [4]. Finally, this result may represent a unique motor adaptation for head-neck stabilization since we showed that the slope between *S* and *T* did not change between both movements. This means that there is no specific muscle adaptation between flexor and extensor (i.e. change for the stiffness index) with different levels of exhaustion in order to stabilize the segment.

CONCLUSIONS

This is the first study assessing head–neck segment musculo-tendinous stiffness with QR perturbations on cervical muscles in extension. We found that the stiffness increases at the same rate according to the exertion level in flexion and extension. The only difference we noted concern the stiffness values, which are inferior in flexion than in extension. These results are novel and give the potentiality to evaluate the head-neck stabilization for different perturbations. They do not confirm specific extensor muscle adaptations other than their own levels of stiffness.

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