Expected scapula orientation error regarding scapula-locator uncertainty while studying wheelchair locomotion

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1. Introduction

Shoulder complex motion is a fundamental aspect of wheelchair locomotion. However, this motion is difficult to capture with skin marker methods due to soft tissue artefacts (Bourne et al., 2011). To overcome this issue, scapula locators (SL), which are external devices equipped with reflective markers and manually registered on the scapula, have been designed (Brochard et al. 2012) To track scapula motion, the SL first needs to be configured as to simultaneously palpate three anatomical landmarks of the scapula: the acromial angle, inferior angle and root of the scapular spine. For static poses, de Groot et al. (1997) and Jafarian Tangrood et al. (2020) studied the impact of palpation incertitude and inter-observer variability on scapula position reconstruction. They reported a scapula angle error in the range of 3.5 – 5 degrees. However, shoulder motions have not been studied yet and the angle error remains unpredictable.

The issue raised in this study was to determine the impact of palpation errors of the scapula's anatomical landmarks when configuring the SL on the reconstruction of a motion-tracking task. Four angles were studied through a constrained multibody kinematics optimization. The study used a Monte Carlo approach and a statistic analysis.

2. Material and Methods

2.1 Experiment

One young able-bodied female was recruited for this study. She was first asked to maintain a static pose allowing one observer to configure the SL based on palpation. Then, she was asked to simulate three cycles of manual wheelchair propulsion movement in a slow motion (with hand gliding on the handrim without exerting force) while her scapula was tracked using the SL by the operator. Four reflective markers were placed on the subject's torso, and five on the SL. Kinematics were recorded for the static and propulsion tasks with a 10-cameras optoelectronic motion capture system (Vicon, Oxford Metrics, UK) at 100Hz.

2.2 Scapula locator initial settings

Alternative SL configurations were simulated using modified palpated points (to simulate differences in inter-observer configurations). *N*=200 new palpated points were created, noising the experimentally palpated points with a zero-mean Gaussian distribution of standard deviation (std) ($\sigma_{settings} = [0{,}5\ 1\ 1{,}5\ 2\ 2{,}5\ 3\ 3{,}5]$ cm) applied to each of the three points. As we assumed that the intra-observer settings error was higher in the scapular plane than in its normal direction, the noise was only applied in the scapular plane.

2.3 Shoulder Model

A musculoskeletal model of the upper trunk and right shoulder was designed and implemented into CusToM, an open-source Matlab toolbox dedicated to musculoskeletal modelling (Muller et al., 2019). The model comprised 13 degrees of freedom (d.o.f.), with 3 d.o.f. for the trunk and 10 d.o.f for the shoulder complex. A scapulothoracic joint was defined as a gliding point on an ellipsoid to allow for the computation of scapula motion (Seth et al., 2016). As a result, the kinematic chain of the shoulder formed a loop which was constrained to remain closed on the acromio-clavicular joint. Geometrical parameters from Dumas et al. (2007) were linearly scaled to the subject size.

The studied scapula d.o.f. were abduction-adduction, elevation-depression, upward rotation and inward rotation. Joint angles were obtained from the marker positions using a constrained multibody kinematics optimization.

2.4 Error quantification

For each d.o.f. k and for each time frame t_i, the std $\sigma_{t_i}^k$ of the error from the *N* draws between the reference angle q^{*k} and the simulated angles q^k was computed. Then for each d.o.f, the mean std estimate σ_{angle}^k was defined as the mean of $\sigma_{t_i}^k$ along the *T* frames. Finally, the total uncertainty evaluator was assessed as follow, based on the estimation error in the Monte Carlo method for *N* draws:

$$|e_{angle}^k| \leq 1{,}96\ \frac{\sigma_{angle}^k}{\sqrt{N}}$$

3. Results and Discussion

An example of scapula kinematics is presented in Figure 1. The three cycles of the subject are visible in the elevation-depression angle. The behaviour of the scapula kinematics reconstruction is similar from a SL setting to another. For each $\sigma_{settings}$ the associated σ_{angle}^k were plotted in Figure 2, with the error bar e_{angle}^k for each

σ_{angle}^{k}. As expected, σ_{angle}^{k} is increasing with $\sigma_{settings}$. A linear model can be used to predict the mean std in the kinematic reconstruction of the scapula for the studied motion. For instance, (de Groot et al. 1997) had a palpation std of maximum 1.1 cm, and reported a mean deviation on scapula abduction of about 2 degrees. With the linear regression, a similar value of 2.8 degrees can be found.

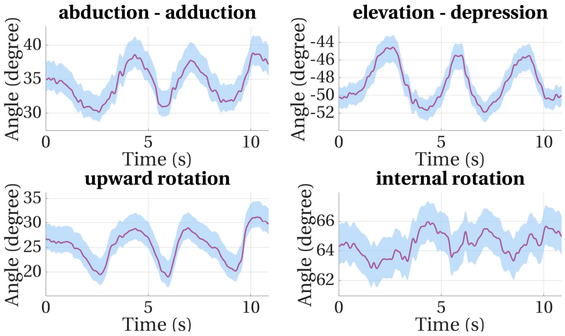

Figure 1 Scapula kinematics: reference angles (thick line) and angle wraps of draws within the σ_{ti}^{k} std (blue background) for $\sigma_{settings}$= 1.5cm

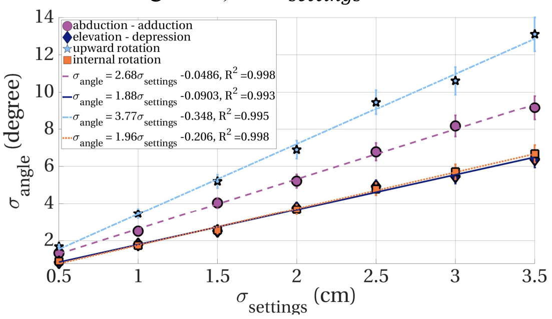

Figure 2 Relation between the std of the SL settings and the std in angle reconstruction

Initial settings error must lie in a 5 mm range to be as accurate as a skin-marker method with a 2 degrees reconstruction error (Bonnet et al., 2017). The wheelchair propulsion movement does not use the full range of motion of the scapula d.o.f. (Figure 1). This study could be extended to a movement that uses the full range of motion, to see if the linear rule could be applied for any movement. During the scapula motion tracking, there are other sources of uncertainties than SL settings: Shaheen et al. (2011) pointed out the impact of the pressure exerted by the observer on kinematics and inter-observer tracking with identical SL settings may affect kinematics. Another Monte Carlo study could be done for the tracking uncertainty, with an appropriate noise distribution on the scapula position at every frame.

4. Conclusions

This study aimed at investigating the influence of the initial SL settings on scapula kinematics reconstruction. This showed the mean std of the scapula d.o.f varies linearly with the std of the SL settings, for a wheelchair propulsion movement.

The focus in this study was made on the SL settings; further studies could extend focus to the whole-body marker positions. As the uncertainty propagation of kinematics to dynamics has been studied (Muller et al., 2017), one could eventually know the impact of the precision of subject equipment to dynamics results.

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