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EVALUATION OF A MULTIPLE CALIBRATION PROCEDURE FOR SCAPULA RECONSTRUCTION

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SUMMARY

The ability of an acromion cluster in conjunction with the calibrated anatomical systems technique (CAST) to reconstruct scapula landmarks with increasing arm elevation has been impaired due to poor congruence between the acromion and cluster. The aim of this investigation was to evaluate the accuracy of a multiple calibration procedure (mCAST) adapted from [1] to reconstruct scapula landmarks. Scapula kinematics from eight participants were recorded within the frontal plane, with both the CAST and mCAST methods evaluated using RMSE. RMSE associated with the mCAST method was lower than the CAST method, particularly at higher angles of elevation by up to 0.028m. Therefore, findings from this investigation support the application of mCAST as an alternative method to increase acromion cluster validity.

INTRODUCTION

Recording of scapula position and orientation is integral to accurate reconstruction of shoulder movement with an acromion cluster in conjunction with the calibrated anatomical systems technique (CAST) commonly advocated [2,3,4]. Whilst a valid method for recording scapula kinematics, differences between palpated and reconstructed landmarks with increasing arm elevation impairs the practical application of this method [4]. Clinically, adaptations [3,4,5] to this method have been proposed but have focused on controlled planar movements that are reliant on first defining scapula orientation. Therefore, the aim of this investigation was to evaluate the accuracy of a multiple calibration procedure (mCAST) adapted from [1] that theoretically not only minimises errors associated with increasing arm elevation but also may be applied to investigate multi-planar movements.

METHODS

After gaining university ethical approval, eight participants (age: 21.9 ± 3.2 years, height: 1.9 ± 0.4 m and mass: 86.0 ± 6.5 kg) with no recent history of shoulder pathology were recruited and provided informed consent.

Whilst standing, scapula kinematics were recorded at 200Hz using an eight camera Vicon MX motion analysis system (Vicon Motion Systems, Oxford, UK) with shoulder position monitored using a real-time biofeedback device. An acromion cluster, composed of three orthogonal retroflective markers was positioned on the acromion plateau to enable evaluation of both CAST and mCAST methods. To establish scapula position at each angle of elevation within the frontal plane (0º, 40º, 80º, 120º, 160º and 180º), anatomical landmarks (Angulus Acromialis (AA), Angulus Inferior (AI) and Trigonum Spinae Scapulae (TS)) were palpated three times by an experienced operator (palpation RMSE: 0.018 ± 0.015m) using a calibrated pointer.

All data analysis occurred within LabVIEW 2011 (National Instruments, Austin, USA). During the initial calibration, at 0º elevation, palpated scapula landmarks (P(PAL)) were defined into the acromion cluster technical coordinate system (ACS) and subsequently reconstructed (P(CAST)) at each of the remaining angles of elevation in accordance with [6] for the CAST method.

$$ {}_{ACS}P(PAL) = {}^{ACS}_{G}T(Pal)^{-1}\ {}_{G}P(PAL) $$
$$ {}_{G}P(CAST) = {}^{ACS}_{G}T\ {}_{ACS}P(PAL) $$

The mCAST method adapts the multiple calibration method proposed by [1] utilising a least squares approach to define a correction factor (c) for each anatomical landmark derived from several static calibrations that are reflective of the range of motion of the movement under investigation. For the purpose of this investigation, the additional mCAST calibrations were based on the palpations recorded at 40º, 80º, 120º, 160º and 180º elevation. The calibration procedure for mCAST requires calculating the difference (d) between the P(PAL) and P(CAST) at each static calibration position in relation to the orientation of the acromion cluster.

$$ d = P(PAL) - P(CAST) $$
$$ {}^{ACS}R\ {}_{G}c = d $$

Using each of the static calibration positions the following can be minimised for each scapula landmark to define c.

$$ {}_{G}c = ({}^{ACS}_{G}R^{T}\ {}^{ACS}_{G}R)^{-1}\ {}^{ACS}_{G}R^{T}[P(PAL) - P(CAST)] $$

The mCAST method subsequently reconstructs anatomical landmarks (P(mCAST) according to the following formula:

$$ P(mCAST) = {}^{ACS}_{G}T\ {}_{ACS}P(PAL) + {}^{ACS}_{G}R\ {}_{G}c $$

Evaluation of CAST and mCAST methods was undertaken through calculating the resultant RMSE in comparison to the palpated scapula anatomical landmarks at 40º, 80º, 120º, 160º and 180º.

RESULTS AND DISCUSSION

Throughout the range of motion, resultant RMSE associated with mCAST (AA: 0.010 ± 0.002m; TS: 0.018 ± 0.004m; AI: 0.028 ± 0.006m) was found to be up to 41% less than the CAST method (AA: 0.015 ± 0.004m; TS: 0.030 ± 0.012m; AI: 0.044 ± 0.012m).

In agreement with [4], a concomitant increase in resultant RMSE was observed with increasing elevation (Figures 1 to 3), however for all scapula landmarks the mCAST method demonstrated an ability to greatly decrease reconstruction error compared to the CAST method. In particular, the mCAST method was observed to minimise errors associated with TS and AI by up to 0.023 and 0.028 m respectively at 160º elevation compared to CAST.

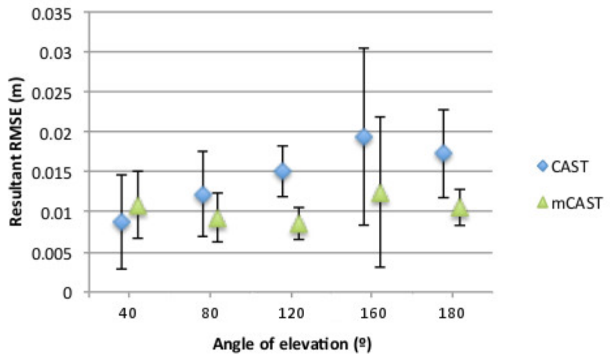

Figure 1: CAST and mCAST resultant RMSE associated with AI within the frontal plane.

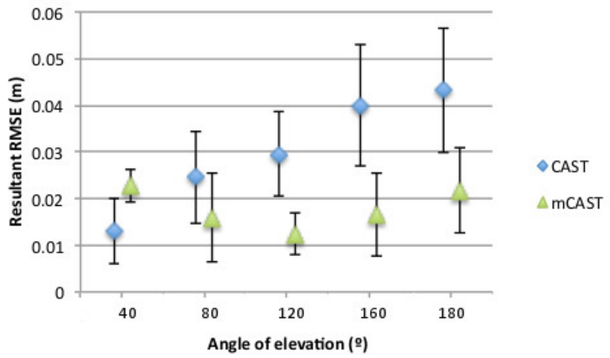

Figure 2: CAST and mCAST resultant RMSE associated with TS within the frontal plane.

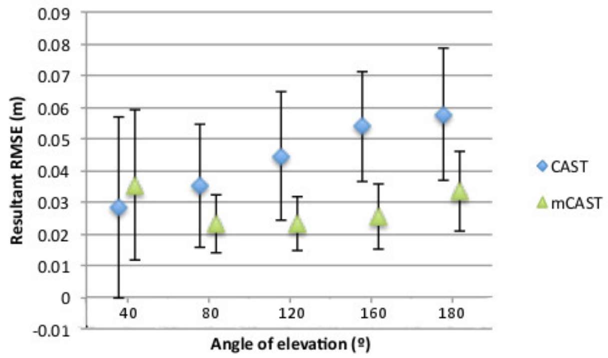

Figure 3: CAST and mCAST resultant RMSE associated with AI within the frontal plane.

As observed within this investigation, the ability of mCAST to acknowledge the non-linear, independent relationship that exists between each scapula landmark and the acromion cluster, advocates the adoption of this method within future research investigating scapula kinematics, particularly those at higher levels of elevation that has been traditionally problematic to researchers. In addition, whilst this investigation focused on evaluating the use of mCAST within the frontal plane, compared to other correction methods [3,4,5], due to correcting scapula landmarks based on the orientation of the acromion cluster, this is the first method suitable for reconstructing scapula kinematics during multi-planar movements.

CONCLUSIONS

The aim of this investigation was to evaluate the suitability of mCAST for reconstructing scapula anatomical landmarks. Findings from this investigation demonstrate that the use of mCAST can decrease resultant RMSE by up to 0.028m at higher angles of elevation when compared to the CAST method. Therefore, the use of mCAST presents an alternative method for the reconstruction of scapula landmarks with use with an acromion cluster that not only addresses the limitations of CAST but also may be applied to multi-planar movements.

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