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**A NOVEL APPROACH TO THE CLASSIFICATION OF SCAPULAR KINEMATICS**

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**SUMMARY**

The complex 3-dimensional rotation of the scapula and the extensive kinematic data produced during motion analysis makes it difficult to objectively classify participants as having movement faults. Classification based on Demspter-Shafer theory of evidence (DST) has been used previously in gait analysis to overcome similar issues, but has not yet been adopted in scapular kinematics. The aim of the study was to adopt the DST method of classifying participants during a motor control test of the scapula. Scapular kinematics were recorded in two groups of participants: healthy control (n=12) and history of shoulder pain (n=6). Six kinematic variables were used as inputs into the DST classifier. The DST successfully classified 5 out of the 6 participants with a history of pain as having movement faults with an accuracy of 72.2% using a leave-one-out cross validation approach. This study demonstrates the use of DST classifier to successfully classify the majority of participants when measuring scapular kinematics during a motor control test.

**INTRODUCTION**

Dynamic control of the scapula is important in the management of neuromusculoskeletal dysfunction of the shoulder. A motor control test for the clinical assessment of dysfunction has been proposed. The test revealed that participants with a history of pain in the shoulder had an increased downward rotation of the scapula during arm lowering [1]. The scapula’s movement, however, is a complex interaction of three rotations, in anyone of which abnormal movement may occur. Additionally the large variation amongst participants makes it difficult to objectively classify participants as having movement faults of the scapula. The Dempster-Shafer theory of evidence (DST), where belief values to a given hypothesis are determined, has been used in gait analysis to solve similar issues [2], but has yet to be adopted in scapular kinematics. The aim of the study, therefore, was to objectively classify participants as having movement faults of the scapula using DST during a motor control test of the scapula.

**METHOD**

Two groups of participants, healthy control (n=12, mean age 31.2 ± 9.5 years), and a group of participants who have had a history of, but not current, shoulder pain (n=6, mean age 44.3 ± 14.7 years) completed a motor control test of the scapula. The test is based on the concept of dissociation which is defined as the ability to control one segment, whilst moving another [3]. The test consisted of manual placement of the scapula into the neutral position (mid-point of all directions of scapular movement) which was held by the participant. The participant then performed arm flexion to 90° elevation, then extension, in the sagittal plane. During the test the participants were asked to maintain control of the scapula. The test was repeated 3 times. Scapular kinematics was recorded at 120Hz using a 6 camera Vicon 460 (Vicon Motion Systems, Oxford, UK) motion capture system. The acromion marker cluster, which has shown to be valid during arm elevation and lowering [4,5], was used to obtain scapular kinematics. Bony landmark, local coordinate systems and Euler angle rotations were defined according to ISB recommendations [6]. Various kinematic data related to the orientation of the scapula at specific points during the test, and principal component (PC) scores of the kinematic waveform [7], were then extracted and used for classification.

The DST classification method as described by Jones et al [2] allows the combination of different variables to arrive at a degree of belief [8,9]. The input variables are converted into 3 “belief values”. These denote the level of belief that a participant has movement faults of the scapula, the level of belief that the participant does not have movement faults, and the level of uncertainty. The results are then represented in a simplex plot where the apex of each point on an equilateral triangle relates to each of the belief values. The triangle is divided into regions of dominant and non-dominant classification. The lower right region classifies the participant as having movement faults. The lower left region classifies the participant as not having movement faults. The top apex of the triangle relates to the level of uncertainty of the classification. The closer the participant to an apex of the triangle, the greater the belief associated with that apex [2]. An objective function was used to rank and therefore determine the most relevant variables to classify participants.

**RESULTS AND DISCUSSION**

Six kinematic variables were used for classification (Table 1), and resulted in a classification certainty score of 72.2%, using a leave-one-out cross validation approach. The highest ranked variables were concerned with upward rotation of the scapula which corresponds well with previous results that found an increased downward rotation at the end of the test [1].

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| Table 1: Ranked variables used in Dempster-Shafer classification |
| Rank | Variable | Confidence factor |
| 1 | Upward rotation at end of test | 77.8% |
| 2 | PC1 score for upward rotation | 72.2% |
| 3 | Upward rotation at rest (before setting to neutral) | 66.7% |
| 4 | Internal rotation at end of test | 61.1% |
| 5 | Internal rotation at start of test | 61.1% |
| 6 | Upward rotation at 90° arm elevation | 61.1% |

All history of pain participants, were classified into the movement fault (lower right) region of the simplex plot, with the exception of one participant (Figure 1). This generally agrees with the physiotherapist’s clinical observation that identified these participants as having movement faults of the scapula. Three healthy control participants, however, were classified into this region. These three participants were not classified as having movement faults by the physiotherapist’s clinical observation, therefore they could be considered as being misclassified by the DST. On further examination, these participants had exhibited upward rotation values at the mid-point (90° arm elevation) and end of the test that were similar to those observed by the history of pain participants. This is the likely cause of them being classified into the movement fault region. Considering the large variability observed in scapular kinematics and the small participant numbers, the DST provided a more than acceptable classification and could be used for future analyses.

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| Figure 1: Simplex plot of DST classification. Healthy (circles) and history of pain (crosses) participants were classified into either movement fault (MF) or non-movement fault (NMF) regions of the plot. The level of uncertainty is represented as participants are positioned towards the top of the plot (NMF, MF) |

**CONCLUSION**

The DST classification method was successful at classifying participants with a history of pain as having movement faults of the scapula during the motor control test. This demonstrates the potential of adopting the DST to provide a way of determining variables that are most discriminatory and be able to confidently identify participants that have movement faults of the scapula.

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