Using stair gait and an objective classifier to identify knee osteoarthritis

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ABSTRACT INTRODUCTION:
Identifying adaptations in joint function is important for monitoring pathology and rehabilitation. Stair ascent and descent requires larger knee joint rotations than level gait and larger forces act through the joint. It is hypothesized that this activity will make functional adaptations due to osteoarthritis (OA) more prevalent and quantifiable. This study determines functional measures from stair gait that differentiate between non-pathological (NP) and OA knee function. These measures are input into a classifier to compute an objective statistical decision of knee function. This produces a visual output differentiating knee function as either NP or OA.

METHODS:
6 subjects with late stage OA (4 females, 2 males, 68 ± 10.2 years, BMI 29.9 ± 2.7 Kg/m²) and 9 NP subjects (5 females, 4 males, 52 ± 10.6 years, BMI 26.3 ± 4.45 Kg/m²) were assessed during stair ascent and descent. After fully explaining the tests, informed consent was obtained from the subjects. Ethical approval was granted by the South east Wales Local Research Ethics Committees and the medical dental school research ethics committee at Cardiff University.

3D Motion capture was performed using 8 ProReflex MCU's (Qualisys, Sweden), capturing at 60 Hz. Force data was captured at 1080Hz from 2 force platforms (Bertec Corporation). Rigid marker clusters containing four retro reflective markers were attached laterally to the thigh and shank of each subject. An anatomical calibration was undertaken using a marked pointer (Holt et al., 2000). A four step staircase was designed and custom built specifically for the study which integrated with a force plate to directly measure Ground Reaction Forces (GRFs). Three trials of stair ascent and descent were recorded. The gait cycle for stair ascent was defined as foot strike on step 1 through to foot strike of the same foot on step 3. The cycle for stair descent was toe off step 3 through to toe off on step 1.

Knee joint axes and rotations were determined according to the Grood and Suntay Joint Coordinate System. GRF’s (normalised to body weight in Newtons) and centre of pressure (COP) coordinates of the foot were computed from the signals generated from the force plate. Sagittal and frontal plane moments acting about the knee joint centre throughout the stance phase were computed from GRF, COP and knee joint centre (Andriacchi et al., 1980). These were normalised to body weight and height and expressed as a percentage. Inertial effects were ignored as they are small in low-velocity activities (Davis et al., 1994).

Kinematic and kinetic waveforms from three trials were averaged for each subject. Knee joint range of motion, peak moments acting about the knee and peak GRFs were determined. Statistical analysis using unpaired independent t-tests (SPSS 12.0.2) was performed on these measures to determine significant differences between the cohorts. This was performed to reduce the vast number of functional variables in preparation for the classifications. Functional variables with a statistical difference between the groups (p<0.05) were retained and Principle Component (PC) analysis was performed on their waveforms (Deluzio, 1997). PCs were used as inputs to an objective classifier (Jones, 2006) to ensure temporal information was retained in the decision making process.

The classifier transforms the functional knee data from each subject into a set of three belief values: a belief that the subjects knee function is non-pathological (mNP); a belief that the subjects knee function is osteoarthritic (mOA); and an associated level of uncertainty (mθ). These are represented as a single point on a simplex plot to give a visual representation of knee function (Figure 1(a)). The distance of the point from each side of the equilateral triangle is in proportion to the belief values. For example, the closer the point is situated to the vertex labelled [NP], the greater the belief that the subject has NP knee function. The simplex plot is divided into four regions (Figure 1(b)) with a central decision boundary illustrated by the dashed line.

RESULTS SECTION:
The OA cohort adapted stair gait for ascent and descent. Statistical differences (p<0.05) in knee function existed between the cohorts. The OA group reduced (i) their peak flexion moment in stance during both stair ascent (OA= 3.53 ± 0.73 %BW*h; NP=5.36 ± 1.04 %BW*h) and descent (OA= 2.95 ± 1.03 %BW*h; NP= 6.77 ± 1.53 %BW*h); (ii) their peak medial GRF during stair ascent (OA= 0.04 ± 0.15; NP= 0.16 ± 0.01); (iii) peak adduction moment during stair ascent (OA= 6.92 ± 3.02 %BW*h; NP= 1.80 ± 0.56 %BW*h); (iv) peak vertical GRF during stair descent (OA=1.05 ± 0.11; NP= 1.31 ± 0.24). PCs of the waveforms from which these measures were selected were used in the classifier. The output is displayed in Figure 2. Knee function of all 6 OA and 9NP subjects were characterised correctly.

DISCUSSION:
Functional variables from stair climbing are important in the classification of OA knee function. Variables determined in this study were able to classify all 15 subjects correctly. 100% classification accuracy was determined using a leave-one-out cross-validation. The variation in stair climbing techniques limited the numbers in our cohorts. It is important to determine the optimum input variables from all stair gait styles to strengthen the classifier.

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REFERENCES:

Figure 1. (a) Relationship between the belief values and position of the point on the simplex plot. h is the height of the triangle. (b) Regions of dominant (1 and 2) and non-dominant (3 and 4) classification.

Figure 2. Simplex plot classifying subject knee function as NP or OA.