

Augmented feedback approach to double-leg squat training for patients with knee osteoarthritis: a preliminary study

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ABSTRACT

The aim of this preliminary study was to explore the effects of two types of augmented feedback on the strategy used by healthy participants and patients with knee osteoarthritis (OA) to perform a double-leg squat. Seven patients with knee OA and seven healthy participants performed three sets of eight double-leg squats: one without feedback, one with real-time kinematic feedback and one with real-time kinetic feedback. Kinematic and kinetic outcome measures (peak knee flexion angle, peak knee extensor moment, and symmetry of the support knee moment between the injured and non-injured knees) demonstrate the potential influence of real-time kinetic feedback on the motor strategy used to perform a double-leg squat in both groups. This feedback could be used to develop more efficient and effective motor strategies for squatting in patients with knee OA and further evaluation is warranted.

1. INTRODUCTION

Knee osteoarthritis (OA) is the most common heterogeneous joint disease. Musculoskeletal pain associated with knee OA can hamper the performance of daily living activities and influence wellbeing (NICE guidelines, 2014, Zhang and Jordan, 2010). Physical performance of daily living activities is an important indicator of the impact of knee OA and resulting pain on individuals' quality of life (Blagojevic *et al.*, 2010, Chacón *et al.*, 2004, NICE guidelines, 2014). There are currently no known treatments to slow the progression of OA; however, physiotherapy is one approach used to improve management of the condition (Bennell *et al.*, 2016, Bennell *et al.*, 2014, Page *et al.*, 2011, Tanaka *et al.*, 2016).

Neuromuscular physiotherapy typically includes physical exercise programmes focusing on strengthening, improving and maintaining aptitude for controlling and regulating postural stability, balance, and muscular strength (Lange *et al.*, 2008), and can improve mobility and strength in patients with knee OA. The exercise programmes require interaction between neural systems and musculoskeletal systems to generate forces to accomplish body movements (Shumway-Cook and Woollacott, 1995, Woollacott and Shumway-Cook, 2005).

Innovative physiotherapy tools are needed to improve physical exercise adherence in individuals with OA and should focus on enhancing self-efficacy and enjoyment. Interventions that consider self-efficacy, maintaining motivation and engagement may successfully achieve functional improvements in patients with OA, who often engage and adhere less in physical activity than non-diseased populations (Bandur, 1997, Vermeire *et al.*, 2001). A possible innovative approach to guide physical exercise performance through feedback and increase patients' engagement is the inclusion of virtual reality into physical exercises (Gokeler *et al.*, 2014, Holden, 2005, Rizzo and Kim, 2005). Virtual reality is a technology that allows a user to interact with a computer-simulated environment, be it real or imagined (Burdea and Coiffet, 2003). Using this technology, we have explored the feasibility of providing in-house-developed real-time targeted feedback of kinetic performance during squatting in game context (Al-Amri *et al.*, 2013).

Considering the importance of implementing a real-time feedback system in a clinical setting, we have developed our targeted feedback application in conjunction with a clinical team. The application is being developed to use simple kinetic data that can be obtained from affordable and simple equipment that is marketed for entertainment purposes, such as the commercial Nintendo Wii balance board (Deutsch et al., 2011, Park and Lee, 2014). We are developing the application for the double-leg squat, as this is commonly used in clinical settings to assess and strengthen muscles around the knee (Escamilla, 2001).

As part of the development process, we are conducting research to understand the influence of two types of feedback (kinematic and kinetic) on the biomechanics of the double-legged squat. The kinematic feedback comprises a stick figure, which represents the subject, being presented on a screen in front of the subject, enabling the subject to view their movement. The kinetic feedback is presented in the context of a game, and requires subjects to focus on the effects of their movements by adjusting the net centre of pressure (COPnet) under their feet to match a target provided on the screen in front of them. The overall aim of this work is to make a preliminary assessment of the effects of an in-house-developed real-time targeted feedback application on the kinetics of a double-leg squat in patients with knee OA. The long-term aim of this research is to determine whether an augmented, real-time, targeted biofeedback approach can aid patients with knee OA by facilitating an effective motor learning strategy and improving self-efficacy.

2. METHOD

2.1 Participant Recruitment

The South East Wales Local Research Ethics Committee approved this research. Inclusion criteria for knee OA patients were: a consultant's diagnosis of knee OA both clinically and radiographically, aged between 18 and 75 years, no previous musculoskeletal surgery in the past 12 months and no other pathologies that affect their movements, no evidence of photosensitive epilepsy, and able to follow simple instructions. Inclusion criteria for healthy participants were: aged between 18 and 75 years and no conditions that affect their movement. Patients were recruited from patients attending physiotherapy clinics.

2.2 Apparatus

The experimental set up comprised the Cardiff Gait Real-time Analysis Interactive Lab system (Figure 1, GRAIL, Motek Medical, Amsterdam, The Netherlands), which consists of an instrumented split-belt treadmill, a 12-camera Vicon MX optical infrared tracking system (Oxford Metrics, Oxford, UK) and synchronised 3D environments that were developed using Google Sketchup (version 8.0, Google, USA). D-Flow software (version 3.20.1, Motek Medical, the Netherlands) was used in the development of the feedback applications and their implementation on the GRAIL system.

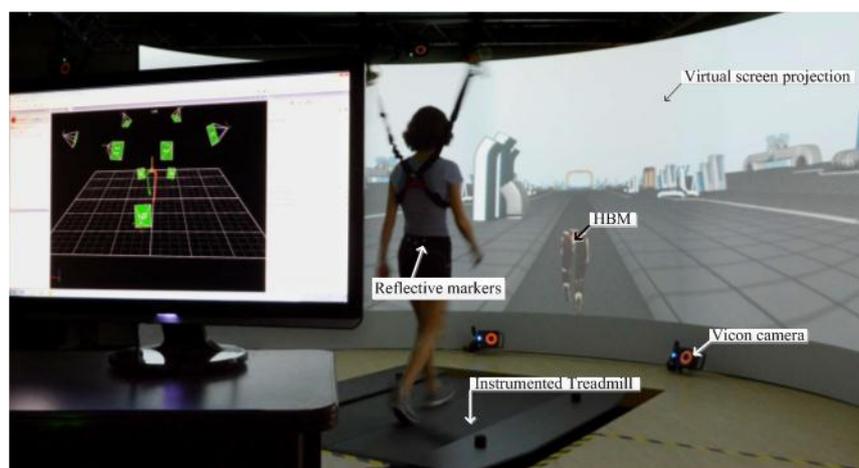


Figure 1. Cardiff Gait Real-time Analysis Interactive Lab.

2.3 Procedure

The investigation was carried out in the Research Centre for Clinical Kinesiology at Cardiff University. On arrival, participants were oriented to the laboratory and the study procedures, and consented to the study protocol if they were happy to participate. Demographic, anthropometric (including height and mass) and relevant clinical information (including condition history and any other related medical conditions that may affect knee OA) were

then obtained via questionnaire and interview. Patients with knee OA completed the Oxford Knee Score, a validated, knee-specific instrument designed to gather opinion about their knee and associated problems, and all participants completed the Tegner Activity Scale form (Tegner and Lysholm, 1985), a validated measure of activity level. Forty-seven reflective markers were placed on anatomical landmarks using the Motek Human Body Model full-body marker set (Motek Medical, the Netherlands).

Each participant performed eight continuous double-leg squats at their comfortable speed and to a comfortable depth under three conditions whilst they were standing on a stationary instrumented treadmill. The first condition was without feedback, the second condition was with kinematic feedback (a real-time stick-figure of the lower limbs presented in a virtual living room; see Figure 2A), and the third condition was with kinetic feedback (net centre of pressure [COPnet] presented as a virtual object on a virtual arrow mat; see Figure 2B). For the kinetic feedback condition, participants were instructed to keep the virtual object as close as possible to the centre of the virtual arrow mat. COP data were obtained through force plates embedded within the stationary treadmill (Forcelink, Culemborg, the Netherlands) and COPnet was calculated in the anterior/posterior (A/P) and medial/lateral (M/L) directions within Motek D-Flow software (version 3.20.1) using equation (1) (Winter et al., 1998). Initial COPnet was computed whilst participants were standing with a body weight evenly distributed across the left and right feet, and was used to calibrate the virtual object.

$$COPnet = COP_l \frac{R_l}{R_l + R_r} + COP_r \frac{R_r}{R_l + R_r} \quad (1)$$

where $COPnet$: net of centre of pressure; COP_l : left centre of pressure; COP_r : right centre of pressure; R_l : left vertical reaction force; and R_r : right vertical reaction force.

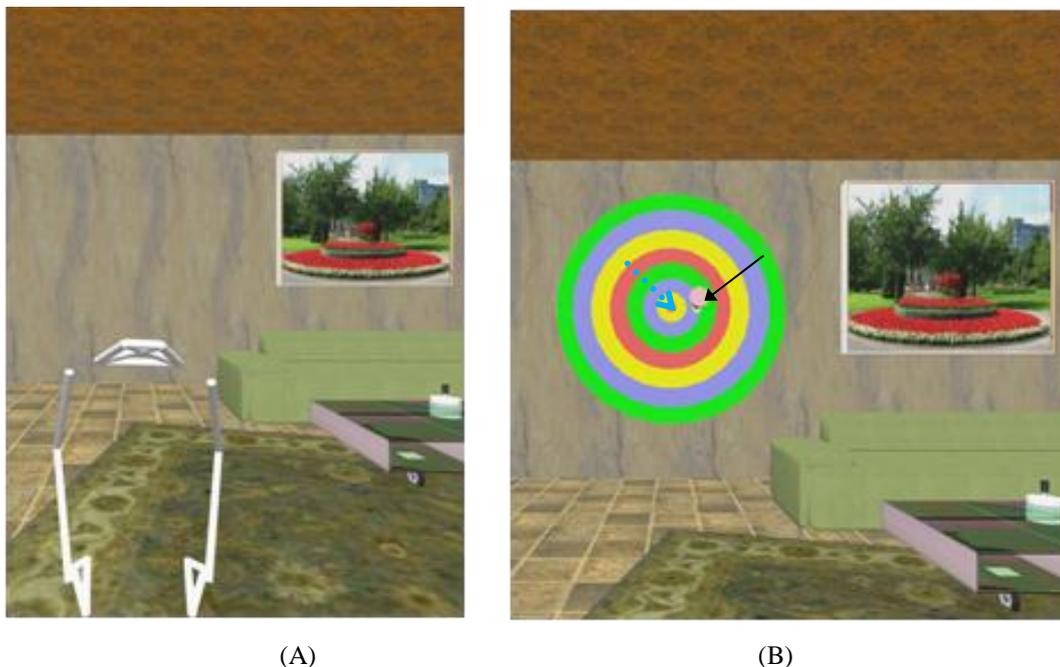


Figure 2. A screenshot of the virtual room during the kinematic feedback condition (A) and the kinetic feedback condition (B). In B the blue arrow refers to the target position (where the symmetry support moment is 100%) and the black arrow refers to the virtual object that driven by the actual symmetry support moment.

2.4 Data Analysis and Processing

Joint and segment angles and moments were calculated using the Motek Human Body Model within D-Flow software (version 3.20.1). The following outcome measures were calculated using Matlab R2015b (Mathworks Inc. USA): peak knee flexion angle, peak knee extensor moment, symmetry of the support knee moment between the injured and non-injured knees (knee OA patients) or between the dominant and non-dominant knees (healthy participants), and total symmetry of the support moment between injured/dominant and non-injured/non-dominant legs. The symmetry support moment (%SYSM) was calculated using equation (2) (Winter, 1990).

$$\%SYSM = \frac{2 * \text{Left Moment}}{\text{Left Moment} + \text{Right Moment}} * 100 \quad (2)$$

As this is an exploratory study with a small sample size we did not undertake any statistical tests within or between groups. Descriptive analysis of all outcome measures and demographic data was performed using Microsoft Excel 2013 (Microsoft, USA).

3. RESULTS

Seven knee OA patients (gender: four males, three females, height: 171.5 ± 7.2 cm, mass: 87.5 ± 17.2 kg, age: 52.1 ± 10.6 years) were compared to seven healthy volunteers (gender: two males, five females, height: 169.4 ± 8.3 cm, mass: 73.1 ± 15.3 kg, age: 45.0 ± 12.4 years). Details of the participants are summarised in Table 1.

Table 1. Participant characteristics. Data are means \pm standard deviation. OA, osteoarthritis; CONT, healthy control participants; OKS, Oxford Knee Score; Tegner, Tegner Activity Scale; BMI, body mass index.

	Age (years)	Height (cm)	Mass (kg)	BMI	OKS	Tegner
Knee OA	52.1 ± 10.6	171.5 ± 7.2	87.5 ± 17.2	29.6 ± 3.8	35 ± 5.1	3.7 ± 2.3
CONT	45 ± 12.4	169.4 ± 8.3	73.1 ± 15.3	25.4 ± 4.1	N/A	6.6 ± 1.4

3.1 Knee Flexion Angle

Figure 3 shows the average peak knee flexion angle for each knee across conditions and groups. The difference between groups in the absence of feedback, with kinematic feedback (stick figure) and with kinetic feedback (COPnet target) was 14° , 15° and 10° , respectively. The greatest variability occurred in the kinetic feedback condition, and was at least 2° higher compared to the first and second conditions across groups. The difference in average peak knee flexion angle between the injured/non-dominant leg and healthy/dominant leg was less than 2° in all conditions.

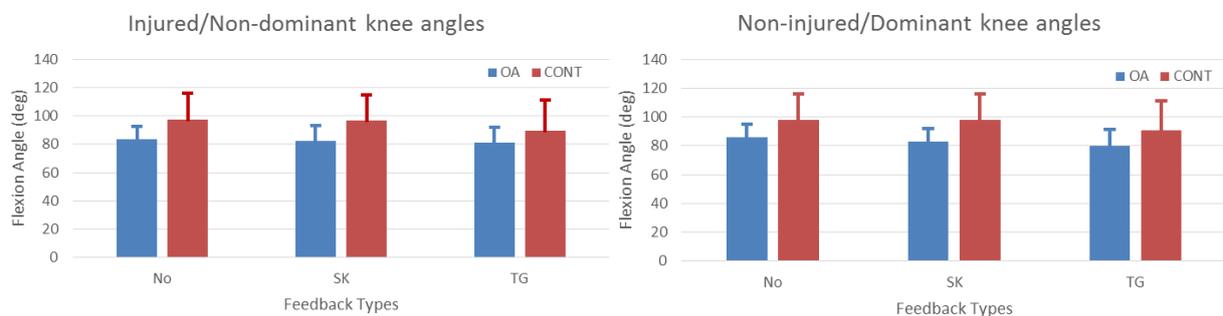


Figure 3. Average peak knee flexion angle. NO, no feedback; SK, kinematic feedback (stick-figure); TG, kinetic feedback (COPnet target).

3.2 Knee Extension Moment

In patients with knee OA, the peak knee extensor moment in the non-injured knee was 0.49 Nm/kg.m with no feedback, 0.47 Nm/kg.m with kinematic feedback and 0.45 Nm/kg.m with kinetic feedback (Figure 4). In healthy participants, the peak knee extensor moment in the dominant knee was 0.45 Nm/kg.m with no feedback and with kinetic feedback and 0.43 Nm/kg.m with kinematic feedback, and in the non-dominant knee was at least 0.02 Nm/kg.m higher in with kinematic feedback than with no feedback (Figure 4).

3.3 Support Moment

In both groups, SYSM was closest to 100% in the kinetic feedback condition. In patients with knee OA, SYSM was higher in the kinematic feedback than in the no feedback condition (93.8%; Figure 5). This was accompanied by a reduction of at least 1% in the contribution of the injured knee to the total SYSM. However, in healthy participants, SYSM was 104.4% with no feedback and 96.5% with kinematic feedback, which was accompanied by an increase of 4% in the contribution of the dominant knee to the total SYSM (Figure 5).

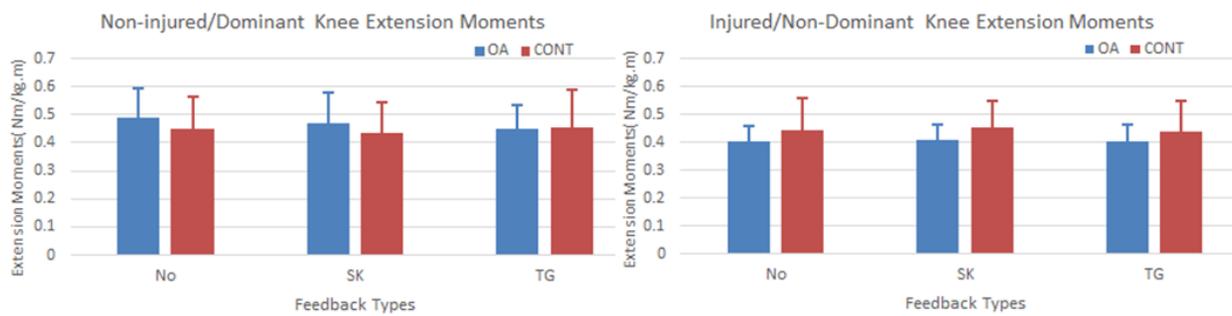


Figure 4. Peak knee extensor moment. Data are the mean of all subjects. Error bars represent standard deviation. NO, no feedback; SK, kinematic feedback (stick-figure); TG, kinetic feedback (COPnet target).

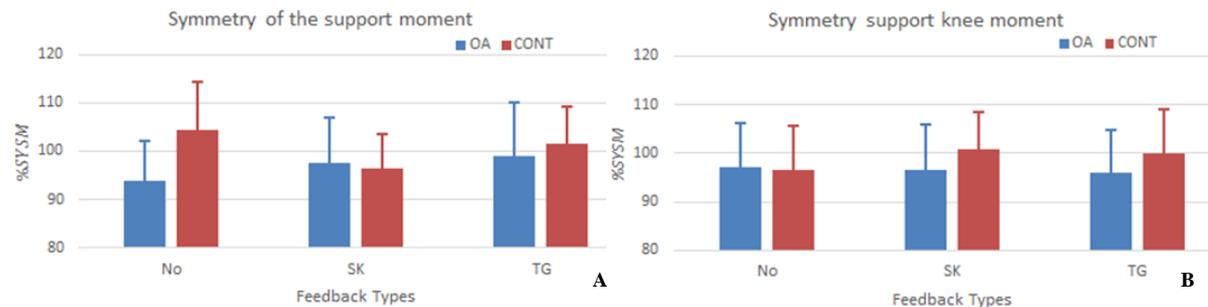


Figure 5: **A:** The total symmetry of the support moment between injured/dominant and non-injured/non-dominant legs. **B:** Symmetry support knee moment between injured/dominant and non-injured/non-dominant knees. Error bars represent standard deviation. NO, no feedback; SK, kinematic feedback (stick-figure); TG, kinetic feedback (COPnet target).

4. DISCUSSION AND CONCLUSIONS

The overall goal of this study was to explore whether an in-house-developed real-time targeted feedback application influenced healthy and OA individuals' motor control strategies during double-leg squatting. Healthy subjects altered their squatting strategy when provided with kinematic feedback in the form of a stick figure of the lower limbs, as evidenced by a SYSM that was 4% lower than 100% in this condition. This is in line with our previous data (Al-Amri et al., 2013) that indicated the percentage of total SYSM in healthy subjects changed when they performed a double-leg squat with stick-figure feedback. Patients with knee OA showed a slightly better distribution of the support moment over both legs when provided with kinematic feedback than when provided with no feedback, as evidenced by a SYSM that was 3% less than 100%. To probe this difference between conditions, we investigated extensor knee moments. Healthy subjects reduced the extensor moment in the non-dominant knee and increased the extensor moment in their dominant knee when provided with kinematic feedback, whereas patients with knee OA only altered the extensor moment in their injured knee. This may suggest that healthy subjects focused on the kinematic information presented to alter their body position during the squat as we observed, where patients with knee OA compensated strategies as they might need to improve the presented information of the injured leg.

In both groups of subjects, motor control strategies improved when kinetic feedback was provided. This is evidenced by the comparable distribution over both legs in the two groups. In patients with knee OA, the extensor moment in the injured knee was much smaller in the kinetic feedback condition than in the no feedback and kinematic feedback conditions. This may indicate that the kinetic feedback encouraged them to use their injured knee. In healthy subjects, squat depth (indicated by peak knee flexion angle) was at least 7° lower in the kinetic feedback condition in healthy subjects than in the no feedback and kinematic feedback conditions. By contrast, patients with knee OA maintained a similar squat depth across all three conditions.

Taken together, these preliminary results suggest that both types of feedback may have a greater effect on patients with knee OA than on healthy subjects. The kinetic feedback may be superior to the kinematic feedback for re-educating an individual on how to best perform a double-leg squat. This is not surprising, as the kinematic feedback presented internal information (i.e. the position of body segments or limbs) whereas the kinetic feedback provided an external focus on individuals' movements (Wulf, 2013, Wulf et al., 2010, Wulf et al.,

2002, Wulf and McNevin, 2003). Further data are required to explicate these effects of feedback type on squatting strategy.

The main limitation of this study is the small sample size, and additional data are needed before firm conclusions that be drawn. We did not investigate the percentage of moment support of the hip, knee and ankle in both legs. Although it is believed that these three joints should contribute to the total support moment in similar amounts in both legs as far as it is 100%, but studying all three joints would uncover which joint is the main contributor to the total support moment. Further clinical research is needed to explore if the differences observed are clinically meaningful.

In conclusion, the preliminary results of this ongoing research highlight the potential of our real-time targeted feedback to promote subtle alterations in movement strategy during double-leg squatting. If deployed in the clinical setting, the methods outlined herein may improve existing assessment procedures and training techniques for motor control, but further longitudinal research on a larger sample size must be carried out. These preliminary results are very encouraging for our on-going research in which we aim to provide evidence to support this conclusion.

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