An investigation into the effects of a simulated effusion in healthy subjects on knee kinematics during jogging and running

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Abstract

Background. Knee joint effusion can lead to changes in the activation of surrounding musculature and result in delayed return to baseline daily and sporting activity following injury. However, the effects of an isolated knee joint effusion on control of movement during cyclical activities such as gait are poorly understood.

Methods. Knee angular displacement and velocity was measured during treadmill jogging (8 km h⁻¹) and running (12 km h⁻¹) in 12 healthy subjects before and after a simulated knee joint effusion. Two separate pre-effusion recordings were taken to account for test–retest variability in gait measurement techniques.

Findings. Subjects demonstrated a small yet significant decrease in peak knee flexion following heel strike at 8 km h⁻¹ as a result of the effusion (P < 0.05). However, there were no significant effects seen at 12 km h⁻¹.

Interpretation. Previous work has suggested that knee joint movement during walking and jump landing is affected by an effusion. However, this work demonstrates that these effects are minimal during jogging and running. Our results suggest that it may be prudent to consider measurement variability in future studies of this nature.

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1. Introduction

Knee joint injuries are commonly associated with activities that demand high levels of stability during dynamic movement. Depending on the mechanism and type of injury, a resultant effusion distends the knee joint capsule resulting in arthrogenic muscle inhibition which may lead to weakness and atrophy in the surrounding musculature (Palmieri et al., 2005). Arthrogenic muscle inhibition is defined as an ongoing reflex inhibition of the musculature surrounding a joint following distension or damage to the structures of that joint (Hopkins and Ingersoll, 2000).

Neuromuscular control at the knee joint is imperative in order to provide stability which allows us to complete everyday activities such as walking, running and jumping. A lack of sufficient control and strength at the knee as a result of arthrogenic muscle inhibition can lead to the development of chronic degenerative conditions (Suter and Herzog, 2000; Lewek et al., 2002), as well as predisposing patients to reinjury (Stokes and Young, 1984). The stimulation of mechanoreceptors located in skin, ligaments, muscles and joints, provides afferent feedback via spinal pathways regarding joint movement and position in various body segments during gait. Interneurons are key components in the spinal circuitry and they function to transmit excitatory and inhibitory signals to other interneurons as well as to alpha and gamma motoneurons (Palmieri et al., 2005). The presence of a knee effusion may affect these signals by altering the alpha motoneuron discharge to motor pathways, resulting in arthrogenic muscle inhibition and subsequent changes in normal movement.

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patterns. However, studies that have evaluated movement characteristics of subjects with knee effusion in their post-injury or pathological state cannot establish whether a change in movement patterns is a direct result of knee pathology or contributed to its etiology.

The majority of the research to date on the effects of knee effusion has used a simulated effusion model to evaluate knee function of healthy subjects in static, non-functional positions. These studies have investigated quadriceps H-reflex (Hopkins et al., 2000; Palmieri et al., 2003, 2005), muscle strength measures (McNair et al., 1996), proprioception (Barrack et al., 1983; McNair et al., 1995) and postural control (Palmieri et al., 2003; Oksendahl et al., 2007). All of these studies have provided important information regarding the effect of effusions on static measures but are not reflective of gross functional motor tasks which require feedback regarding movement and position during multiple joint movement such as gait. A small number of researchers have investigated lower limb movement patterns during functional activity in healthy subjects following a simulated effusion. Palmieri-Smith et al. (2007) investigated the effects of an effusion on movement patterns and electromyographic (EMG) activity during a drop landing in healthy subjects. They observed a more extended knee position upon landing and a reduced knee extension moment and quadriceps EMG activity post-impact compared to baseline and the injection of lidocaine. The authors hypothesised that a reduction in EMG activity, and therefore weakened quadriceps following an effusion, altered landing mechanics causing a greater amount of knee extension and therefore large forces to be transferred through the knee. Marshall et al. (1993) observed two distinctly different patterns of change in ankle joint movement during walking following effusions of 30, 60 and 90 ml in the knee joint yet no consistent group effect. No kinematic changes were found at the hip and knee joints. However, Torry et al. (2000) found that a knee effusion of 50 and 80 ml resulted in small yet significantly increased flexion at heel strike and greater average flexion throughout the stance phase at both the hip and the knee during walking. Another recent study by Torry et al. (2005) investigated the effects of a 20 ml effusion at the knee and demonstrated no change in the average knee angle during the stance phase of jogging despite a reduction in quadriceps EMG activity in the majority of their subjects. The lack of a consistent pattern in the results of studies suggests that further work is required to understand how the neuromuscular system responds to the presence of an effusion in functional activities further investigation is needed.

A possible explanation for the lack of consistent results from these studies may be due to potential test–retest measurement errors associated with kinematic studies (Monganhan et al., 2007) and the fact that multiple functional activities have not been examined in the same subject group in a single study. In assessing the effect of an effusion, observed differences in joint movement must be greater than test–retest variance for an effect to be true. The aims of the present study were to address potential measurement error by performing a kinematic analysis on healthy subjects on three occasions – twice prior to and once post a knee joint effusion. Furthermore, in an effort to establish the consistency of effect at different running velocities we have analysed knee movement during both jogging and running. The effects of an effusion may be better observed in these activities as they place notable stress on the knee and require a greater activation of the quadriceps to control the knee joint.

2. Methods

2.1. Subjects

Twelve physically active subjects were recruited from the local university population for the purpose of this study (Table 1). The inclusion criteria required subjects to be aged between 18 and 40 years inclusive and to be regularly participating in training or physical activity with no current injury complaints. Subjects were excluded from the study if they had sustained a lower limb injury/trauma in the previous 3 months for which they had received medical advice/treatment, were currently taking any medication that may have interfered with their neuromuscular system, complained of current knee pain or lower extremity weakness or numbness, had a history of surgery, rheumatologic or orthopaedic disorders and if they were pregnant. Each subject was asked to rest from physical activity and also to refrain from the consumption of alcohol in the 24 h prior to data collection. The university ethics committee approved the study and written informed consent was obtained from each subject prior to participation in the study.

2.2. Test protocol

All procedures, including gait analysis and knee effusion protocol, were carried out in the university motion capture laboratory. Prior to the initiation of the testing session a general explanation of the study and its significance was provided as well as an explanation of the testing procedures and protocol. Subjects then underwent a 10 min familiarisation session on the electrically driven treadmill (RTM 500, Biodex Medical Systems Inc., New York, USA) at velocities of 4 and 8 km h\(^{-1}\) for 5 min, respectively. All subjects had previously used a treadmill. Data was recorded in three measurement intervals throughout the testing session, twice prior to the effusion, Control 1 (C1) and Control 2 (C2), and once following the effusion, Post-Effusion (PE). Ten minutes rest was allowed between

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the two control tests and following the injection of fluid into the knee and the PE test. Kinematic data was collected at a sampling rate of 200 Hz for 20 s at velocities of 8 and 12 km h\(^{-1}\). A treadmill velocity of 8 km h\(^{-1}\) was chosen based on a previous study by Nilsson and Thorstensson (1989) who have demonstrated that the transition from walking to running occurs at a velocity of approximately 7.2 km h\(^{-1}\). The 12 km h\(^{-1}\) velocity was chosen as a speed that would be reflective of most subjects assuming a running type gait pattern rather than jogging. Data were collected while subjects ran continuously during a 1.5 min period at each velocity with two 20 s blocks of data recorded at each velocity in each testing interval. The treadmill was stationary in between tests, allowing the subject a recovery period of 1.5–2 min between testing at each velocity. The initial point of acquisition was taken once the subjects were comfortable at the given velocity. Subjects were not aware of the precise period of data acquisition. Subjects wore their normal training shoes for the tests. A trial was terminated if a marker or wand became loose and was reapplied in the same position in accordance with markings made on the subject’s skin before the test recommenced.

2.3. Motion analysis acquisition

We used an active marker based motion capture system (CODA, Charnwood Dynamics Ltd., Leicestershire, UK) to acquire kinematic data during gait. Internal joint centres for the lower limb were calculated by obtaining the following anthropometric data: the pelvic width from the left anterior superior iliac spine to the right anterior superior iliac spine; the pelvic depth from the anterior superior iliac spine to the posterior superior iliac spine; the knee width and the ankle width. Measurements were recorded in millimetres using a calliper (Lafayette Instrument Co. Europe, Leistershire, UK). The limb lengths of the thigh, the shank and the foot were determined using a measuring tape. The subjects’ height and weight were also acquired. The CODA markers and the marker wands were applied in accordance with the manufactures guidelines for gait analysis by the same investigator on all subjects. Markers were positioned on the lateral aspect of the knee joint line, the lateral malleolus, the heel and the fifth metatarsal head. Wands with anterior and posterior markers were positioned on the pelvis, sacrum, thigh and shank. The markers were fixed to the skin with velcro and double-sided adhesive tape.

2.4. Knee effusion protocol

Following the completion of the two initial control trials, C1 and C2, the subjects underwent a simulated knee effusion procedure. Each subject was individually screened by the medical doctor prior to the injection of fluid into the knee. The subject was placed in a crook lying position with their test limb fully extended on a plinth. The area around the knee was cleaned with alcohol and 10% povidone iodine solution in preparation for the injection. Injections were undertaken by the same physician. Two millilitres of 2% Lidocaine was injected subcutaneously laterally to the knee joint line for anaesthetic purposes. Care was taken not to penetrate the joint capsule during the anaesthetic injection. Thereafter, 60 ml of saline solution (0.9% (w/v) sodium chloride intravenous infusion) was injected into the knee joint capsule. A lateral midpatellar approach using a 21-gauge 2-in. needle was used in this study. This approach has been shown to have a 93% accuracy rate in a study using real time fluoroscopic imaging (Jackson et al., 2002). Following the injection, the area was again cleaned immediately with an alcoholic wipe and a sterile dressing was applied. A ballotable patella test and an effusion wave test were performed to ensure that the effusion was within the knee joint (Palmieri et al., 2003). Subjects were then assisted in standing upright and were instructed to weight bear fully on the leg.

2.5. Data and statistical analysis

Kinematic data of the injected knee was analysed by calculating the angular orientations of the coordinate systems of the adjacent limb segments. Joint angular displacements and velocities were calculated for the sagittal (flexion/extension) and coronal (internal/external rotation) planes of motion. The point of heel strike was identified for 10 consecutive running cycles as the point at which the vertical acceleration of the lateral malleolus marker crossed the horizontal axis of the graph for a particular gait cycle. This method of identifying heel strike has been shown to be accurate for treadmill running (McElvaney, 2006). Sagittal and coronal knee angular position and velocity at heel strike, and peak values for these variables during the 250 ms period prior to and following heel strike were identified. These values were then averaged over 10 cycles for each subject at both 8 and 12 km h\(^{-1}\) during each test interval.

Statistical analysis was carried out using SPSS for Windows (Version 12.0.1; SPSS Inc., Chicago, IL, USA). We used a general linear model three factor repeated measures analysis of variance to analyse differences in kinematic variables at each of the test intervals. In each case the dependent variable was the kinematic variable in question and the independent variables were test interval (C1, C2 and PE). Post hoc paired \(t\)-tests were then carried out to test for differences kinematic variables between individual pairs of test intervals (C1vC2, C2vPE, C1vPE). The alpha level was set at 0.05. Due to the potential for multiple comparison errors, we used a modified Bonferroni adjustment as described by Hochberg (1988) to re-calculate the \(P\) value for the repeated measures and post hoc \(t\)-tests.

3. Results

Repeated measures ANOVA revealed a statistically significant difference (\(P < 0.004\)) with a decrease in peak knee
We also observed a number of small yet statistically non-significant differences in a number of variables between the different test conditions at 8 and 12 km h\(^{-1}\) (Tables 2 and 3) and pairwise post hoc comparisons revealed that the only comparison to reach the level of significance was that of a decrease in peak knee flexion 250 ms post-HS at 8 km h\(^{-1}\) during C1 versus that PE (\(P < 0.001\)). No other significant differences were found in a range of variables at velocities of 8 and 12 km h\(^{-1}\). There were no other significant differences. No subjects reported feeling pain during the injection procedure. Two female subjects only received 55 ml of fluid having complained of a feeling of ‘tightness’ and did not wish for further fluid to be administered into the joint. These subjects were included in the data analysis as it was felt that in proportion to the anatomical size of their knee that such an amount represented a similar effusion to other subjects who accepted the full 60 ml.

4. Discussion

The principal finding in this study was that of a significant decrease in peak knee joint flexion in the period immediately post-heel strike during jogging following a simulated knee effusion of 60 ml. This period is referred to as the initial load bearing response during the stance phase and serves to reduce the impact on the lower limb and smooth the centre of mass displacement during weight transfer, thereby reducing energy expenditure and forces on the knee joint (Lucareli and Greve, 2006).

Previous studies investigating lower limb muscle activity during gait have observed changes in muscle activity in
injured (Bulgheroni et al., 1997; Rudolph et al., 2001; Hurd and Snyder-Mackler, 2007) and healthy subjects (Marshall et al., 1993; Torry et al., 2000, 2005). The observed decrease in knee flexion may have been due to quadriceps inhibition following the effusion that resulted in an associated change in the knee flexion angle. Authors have described patients as having a ‘quadriceps avoidance type gait pattern’ due to the inability of the quadriceps to be activated following effusion. Torry et al. (2000) established that such a pattern occurred following an effusion throughout the stance phase during jogging and Palmieri-Smith et al. (2007) have also observed a more extended knee position during a drop landing activity. Another study undertaken by Torry et al. (2005) used only 20 ml of fluid and although a reduction in vastus medialis and lateralis activity was seen, no changes were observed in average knee joint angle during the stance phase. However, using higher levels of effusion, our findings indicate that quadriceps avoidance type patterns of movement do occur during jogging. Therefore, higher levels of effusion may be necessary in order to elicit changes in movement patterns.

There are a number of potential reasons why minimal significant results were observed in this study. Torry et al. (2005) proposed that inertial forces experienced by the lower limb during jogging are significantly greater compared to walking, to the extent that they may override the quadriceps inhibition associated with the effusion. Similarly, neuromuscular adaptations may have occurred during running compared to jogging when higher levels of effusion are used as in our study. The afferent response of mechanoreceptors located in and around the joint which act on spinal neurons may be reduced by descending tonic inhibition (Cevero et al., 1991). This descending inhibition may increase due to the effect of the effusion on mechanoreceptors, such that the knee is maintained in normal ranges of motion to reduce potentially injurious movements during running. Palmieri-Smith et al. (2007) suggest that muscle activation provided by the uninhibited rectus femoris may compensate for inhibited muscles to maintain normal movement. Therefore, different motor strategies may be utilised to accomplish typical movement patterns during jogging and running which require greater levels of stability and control at the knee.

Another possible reason for the minimal changes observed may have been the level of the effusion. We used an effusion of 60 ml as previous research has demonstrated that an effusion of as little as 20 ml results in inhibition of vastus medialis and 60 ml results in inhibition vastus medialis and lateralis (Spencer et al., 1984). Our results did show that there was a difference in knee angle during jogging as opposed to no significant kinematic findings in the Torry et al. (2005) study using 20 ml. Even though these levels of effusion may be considered of importance in a clinical setting, they may not be sufficient to elicit major changes in movement patterns during high velocity tasks in healthy subjects. The presence of an effusion with associated inflammation and pain in acute and chronically injured subjects may be responsible for the loss of proprioception and muscle inhibition as observed in clinical situations. Owing to the long term presence of an effusion, adaptations to learned movement patterns may result in the ‘quadriceps avoidance’ type movement strategies. Future studies in this area should use varying levels of effusion in a range of functional and sports specific activities to ascertain the effects of effusion on movement patterns and rehabilitation. We did not measure the pressure of the fluid in the capsule throughout the testing procedure and fluid was not aspirated following completion of the tests. Imaging equipment was not available to us to confirm the presence of fluid within the joint. Therefore, we cannot assume that all of the fluid remained in the capsule and did not absorb into the surrounding area.

We believe that our measurement protocol provides a strong basis for future studies to conduct their investigations in this area. We undertook to examine peak measures in the gait cycle in three separate measurement intervals in order to address the issue of test–retest variance that is inherent in kinematic studies (Monaghan et al., 2007). Had we employed a straightforward test-effusion-retest model we would have arrived at a different set of conclusions to those presented here.

There are also a number of limitations of this study which need to be addressed. Two subjects were injected with less than 60 ml of saline as they complained of tightness in the knee which made them uncomfortable. These subjects were included in the data analysis as we concluded that they had accepted the maximum amount of fluid which their knees could accept in that particular testing session. These subjects demonstrated similar patterns of movement to the majority of the subjects tested. The effusion model used in this study does not account for variability in that different size subjects will have different sized capsules creating a variation in capsular pressure, which may influence the degree of inhibition observed. The paucity of significant functional differences in joint position and velocity may be accounted for by the repetitive and constant speed provided by a motorised treadmill. Coupled with this, the regularity of the surface of the treadmill could result in the neuromuscular capabilities of the lower limb during movement not be fully tested compared to an overground situation. Previous studies have found differences in kinematics when comparing overground with treadmill gait in normal subjects (Wank et al., 1998; Schache et al., 2001). Numerous studies have demonstrated changes in lower limb kinematics following knee injuries such as ACL injuries, which are generally accompanied by an effusion (Bulgheroni et al., 1997; DeVita et al., 1997; Rudolph et al., 2001; Kurz et al., 2005; Hurd and Snyder-Mackler, 2007). These studies have observed the effects of a chronic effusion after traumatic events and/or surgical intervention. The effusion model has the advantage of nullifying other factors of injury, pain and inflammation which are difficult to quantify (Hopkins, 2006). However, it assesses subjects in an acute situation and therefore has limited application to chronic injuries in a clinical setting.
5. Conclusions

Previous studies in the literature have observed altered patterns of movement and muscle activity following a simulated effusion, which may negatively affect knee stability and potentially increase susceptibility to further injury. In the present investigation, knee joint kinematics during treadmill jogging altered following a simulated knee joint effusion of 60 ml. Subjects had a decrease in knee flexion which may impede the ability of the knee to absorb forces and cause larger forces to be transferred through the knee joints passive structures. No other changes were observed in a range of other variables in this setting. This study has implications for gait analysis methodology for future studies. The findings of this study highlight the need for further investigation into motor control following a simulated knee effusion.

Conflict of interest statement

The authors do not have any financial and personal relationships with other people or organisations that could inappropriately influence (bias) this work.

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