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INFLUENCE OF SURGERY AND REHABILITATION CONDITIONING ON PYCHOPHYSIOLOGICAL FITNESS.

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Abstract

The purpose of this study was to assess changes in psychophysiological fitness following reconstructive knee surgery and early phase (2.5 months) physical rehabilitation. Nine patients (7 male, 2 female, mean age 29.9 years) electing to undergo ACL-reconstructive surgery (central third, bone-patella tendon-bone graft) were assessed on 4 separate assessment occasions post-surgery.

Repeated measures ANOVAs showed significant condition (injured/non-injured leg) by test occasion (2 weeks pre-surgery and 6, 8, and 10 weeks post-surgery) interactions for knee ligamentous compliance (anterior tibio-femoral displacement), peak force and electromechanical delay associated with the knee flexors of the injured and non-injured legs ($F_{(3, 24)} = 4.7$ to 6.6; $p < .01$), together with individualised emotional profile disturbance scores that were significantly less at 10 weeks post-surgery compared to pre-surgery, 6 weeks and 8 weeks post-surgery ($F (3,24) = 7.6$; $p < 0.01$). Spearman rank correlation coefficients identified significant relationships between musculoskeletal fitness and emotional profile scores at pre-surgery ($r = 0.69 - 0.72$; $p < 0.05$) and at 8 weeks post-surgery ($r = 0.70 - 0.73$; $p < 0.05$). The 6 Bi-POMS subscales and the 12 ERAIQ responses found inconsistent patterns of response and relationships across the assessment occasions.

Overall, the patterning of changes and associations amongst emotional performance profile discrepancy scores in conjunction with those scores from indices of musculoskeletal fitness performance capability, offered important support for the efficacy of an approach integrating self-perceptive and objective measurements of fitness capability during rehabilitation following surgery to a synovial joint.

Key words: psychophysiology, rehabilitation, musculoskeletal fitness.

Introduction

The proposed outcomes of improved compliance by patients to rehabilitation programmes and improved clinical outcomes has meant that pychophysiological fitness and rehabilitation in response to physical injury has become a primary concern for performers and the sports medicine team in recent years (Gleeson et al., 2005; Doyle et al., 1998). A number of theories have been proposed to interpret and explain pychophysiological adjustment to athletic injury. Stage models of grief and loss (Brown and Stroudmire, 1983) have relied upon to explain psychological reactions to injury (Rotella and Heyman, 1993; Lynch, 1988; Pedersen, 1986). Other research has suggested that emotional reactions to injury may be far more complex and varied across individuals (Brewer, 1994; Pearson and Jones, 1992; Wiese and Weiss, 1987). Thus despite the popularity and potential predictive utility of stage models, they may be unable to fully incorporate complex responses including changes to musculoskeletal and psychophysiological fitness capabilities within their relatively simple frameworks.

Cognitive appraisal models were developed to a large extent to explain heterogeneity of responses and individual differences for which stage models were unable to account (Lazarus, Folkman, 1984; Rotella, 1985; Wiese-Bjornstal and Smith, 1993). It has been proposed that the way an individual interprets an athletic injury determines the emotional response. Cognitive appraisals (or interpretations) have been thought to be influenced by the interaction of personal factors (i.e., dispositional and/or historical attributes of the individual) and situational factors (i.e., injury-related characteristics [including current musculoskeletal fitness capability] and aspects of the social and physical environments). Despite the promise for an approach that examines the joint influence of personal and situational factors on psychological responses to injury (Brewer, 1994), there are potential logistical problems of evaluating athletes on all the variables mentioned in stress models.

The ultimate aim of a pychophysiological assessment is to identify individual emotional areas of need within the context of changes to musculoskeletal fitness. These areas can then be used to modify both physical conditioning and emotional rehabilitation accordingly in order to optimise the rate and extent of an individual's physical and psychological recovery. A number of scales have been developed which require athletes to rate their emotional mood state. The most popular scale is the Profile of Mood States (POMS) (McNair, Lorr, Droppleman, 1971). The original POMS has been updated and the new version, the Bi-polar Profile of Mood States (POMS-BI), has become popular (Lorr, McNair, 1988) Although POMS and Bi-POMS are frequently used to monitor performers' emotional responses during fitness conditioning and rehabilitation, they are not injury-specific and were developed originally for applications in psychiatry. Psychometric measures that have been developed specifically to measure performers' emotional responses to injury, such as the Emotional Responses of Athletes to Injury Questionnaire (Smith et al., 1990) may be more apposite.

The anterior cruciate ligament (ACL) is the principal ligamentous restraint to anterior tibio-femoral displacement (Butler et al.,1980) and is the most commonly injured of the major knee joint ligaments (Tibone et al., 1986). Despite advances in surgical treatment and rehabilitation programmes, ACL injury still presents extensive physiological and psychological challenges to the performer (Sanderson, 1996; Wiese and Weiss, 1987). Anterior tibio-femoral displacement (ATFD) is a key marker of knee joint stability and ACL performance and is assessed subjectively in contemporary clinical practice by the surgeon and can be assessed objectively using instrumented knee devices (Gleeson et al., 1995). Similarly, peak force and electromechanical delay were selected as markers of capability for strength fitness and the maximum rapidity with which physiologically meaningful levels of force could be initiated to help stabilise a joint system, respectively. Electromechanical delay is comprised of several events associated with excitation contraction coupling and the rate at which the series elastic component of muscle may be stretched and as such, can offer a potentially important insight into the musculoskeletal performance of a joint system (Gleeson, 2001).

Studies have employed both POMS and ERAIQ to assess the emotional responses of performers undergoing ACL-reconstructive surgery and showed significant changes in emotional responses following surgery and during the subsequent rehabilitation period (LaMott, 1996; Morrey, 1996). Despite the popularity of questionnaire assessments of emotional responses during periods of fitness conditioning, it could be argued that a questionnaire cannot fully reflect the diversity of idiosyncratic responses (Pearson and Jones, 1992). For example, May and Sieb (1987) listed 40 emotions that had been observed clinically following physical injury and it seems unlikely that any predetermined measure would be able to identify this range of emotions. Additionally, an exercise scientist working in contemporary practice ideally requires a ‘user-friendly’ assessment of performers' emotional state that is not time-consuming operationally and which can be acquired alongside estimates of musculoskeletal fitness performance.

The 'emotional profile' is an adaptation of the performance profile technique (Gleeson et al., 2005). Personal construct theory underpins the emotional profile and emphasises the idiosyncratic nature of responses (McCoy, 1977; Kelly, 1955). The emotional profile caters for the importance of individual’s emotions and encourages the use of adjectives generated by the performer to represent meaningful descriptions of emotional experiences.

Despite the potential efficacy of this technique, results from studies investigating its measurement utility have suggested that the performance profile may have limited measurement sensitivity in populations where small changes in the strength of emotions and performance are expected, such as the elite performer during the competitive athletic season (Gleeson et al., 2005; Doyle and Parfitt, 1999; 1997; 1996). However, these studies suggest that the emotional profile would be expected to have greatest measurement utility for guiding pychophysiological interventions in populations where larger changes in emotional state and physical fitness capability would be expected, such as the novice performer or the performer recovering from sporting injury. The profile would allow the adjectives chosen by each performer to be presented onto an individualised visual display and to allow performers to rate their current emotions and psychophysiological fitness capability within this framework. This method of display makes information easily digestible for the performer and the sports medicine or fitness monitoring team. It also allows the performer to rate him/herself on elements that readily make sense as opposed to responding on predetermined measures. The assessment of the efficacy of tools to measure concomitant emotional and physical responses to injury and subsequent rehabilitation would potentially assist in the evaluation of the outcomes of interventions used in contemporary clinical practice.

The purpose of this study was to assess contemporaneous changes to estimates of pychophysiological fitness capability in individuals with unilateral ACL knee-injury that have undergone reconstructive surgery and a subsequent early phase (2.5 months) of standardised physical rehabilitation conditioning.

Methods

Participants.

Nine sporting performers (7 male [mean height = 1.73 m ± 0.07 m; mean weight = 81.5 kg ± 5.8 kg], 2 female [mean height = 1.65 m; mean weight = 66.2 kg ± 7.8 kg]) electing to undergo ACL-reconstructive surgery at a U.K. National Health Service Trust hospital gave their informed consent to participate in this study. Participants ranged in age from 16 to 44 years, with a mean age of 29.9 ± 8.7 years. Participants were treated by the same consultant orthopaedic surgeon. They were chosen randomly from a series of 50 patients presenting with arthroscopically verified unilateral complete ACL-rupture seen at the hospital over a four month period. All participants were scheduled to undergo the same standardised reconstructive surgery procedure (central third, bone-patella tendon-bone graft).

The participants included a former national soccer player, a county level soccer player, 1 county netball players, 3 county level rugby players, 1 recreational squash player, 1 recreational skier, and 1 regional standard judo player. Of the 9 participants, 7 had injured their left knee. One participant had obtained the injury during normal activities of daily living, 4 participants had obtained the injury via a non-contact incident whilst performing sport and 4 via a contact incident during sport. On average participants had waited 20.4 ± 13.2 months following the initial injury incident before undergoing reconstructive surgery. The Ethics Committees for Human Testing of Leighton Hospital NHS Trust and Robert Jones and Agnes Hunt Orthopaedic and District Hospital NHS Trust, approved assessment protocols.

Experimental procedures.

The experimental design involved repeated measures and comprised a single-leg intervention (reconstructive ligament surgery and a subsequent acute phase (2.5 months) of standardised physical rehabilitation) and contralateral limb control model. Participants were verbally encouraged during periods of maximal muscle activation. Estimates of knee flexor volitional neuromuscular performance, musculoskeletal performance, knee function ratings and self-perceived physical performance capability were obtained at each assessment occasion. The protocol is illustrated schematically in figure 1.

- Insert Figure 1 here –

Clinical interventions.

Following the standard surgical intervention (arthroscopic ACL-reconstruction [bone-patella tendon-bone graft] performed by the same surgeon), participants followed a standardised rehabilitation programme (see Table 3). During the early stages of rehabilitation (0 - 6 weeks post-surgery), standard rehabilitation exercises concentrated on gaining full range of motion in the injured limb, and hamstring exercises progressing to cycling, step-ups and proprioceptive activities. During the intermediate stage, proprioceptive work was increased, figure-of-eight circuits were introduced and the difficulty of other activities (e.g., step-ups, one-legged dips) was increased. Participant compliance to this standard programme was excellent as verified directly by the physiotherapists and corroborated by self-report diaries from participants. Any localised recommendations by the clinical team for deviations away from the guidelines for individual patients were undertaken in accordance with professional clinical judgements.

Monitoring of physical rehabilitation and activity was undertaken throughout the assessment period. Participants were asked to complete a weekly rehabilitation diary commencing from the day of surgery to 10 weeks post-surgery. Participants were asked to record the number of rehabilitation sessions completed each day and the total daily time spent performing rehabilitation.

All instructions to participants were given by means of standardised written instruction cards. Participants were not given feedback of results until after the completion of the prescribed number of test occasions.

Assessment procedures.

During an initial meeting with the researcher, an individual performance profile of the knee was elicited from participants. Participants were assessed on 4 separate testing occasions. The first occasion was 2 weeks prior to surgery and the second, third and fourth occasions were 6 weeks, 8 weeks and 10 weeks following surgery, respectively. The first testing occasion included a familiarisation session and was devised to obtain baseline pre-surgery measures of musculoskeletal fitness and emotional mood state. The post-surgery testing occasions were designed to correspond with the most rapid period of physical improvement associated with the rehabilitation process.

On each separate testing occasion, participants completed the IKDC (subjective and symptoms sections), the ERAIQ, the Bi-POMS, and an individualised emotional profile associated with the involved knee. The physiotherapist and consultant orthopaedic surgeon completed the range of motion and ligament examination sections of the IKDC for each participant, respectively. Subsequently, participants undertook a standardised warm-up. They were then assessed on estimates of musculoskeletal fitness including knee ligamentous compliance (anterior tibio-femoral displacement [ATFD]), peak force (PF), and electromechanical delay (EMD) of the knee flexors in the injured and non-injured legs in random order.

Following habituation procedures, participants completed a standardised warm-up of five minutes cycle ergometry (90 watts for males, 60 watts for females, as tolerated clinically by participants) and a further five minutes of static stretching of the involved musculature. Participants were then secured in a seated position on a custom-built dynamometer and arthrometer (Gleeson et al. 1995; Gleeson, 2001).

Participant and dynamometer orientation.

The bi-lateral lever-arms of the dynamometer were attached to the legs of the participant by means of padded ankle-cuffs and adjustable strapping just proximal to the lateral malleolus. The dynamometer's and knee joint's axes of rotation were aligned as closely as possible. Adjustable strapping across the mid-thoracic spine, pelvis and posterior thigh proximal to the knee localised the action of the involved musculature. A functionally relevant knee flexion angle of 25 degrees (0.44 rad) associated with the greatest mechanical strain on key ligaments (Beynnon and Johnson 1996), was maintained throughout testing. This angle was identified for each participant during activation of the involved musculature using a goniometer system. Once secured into position and prior to testing, participants were required to perform a series of warm-up muscle activations of the knee flexors, comprising of 2 x 25%, 50%, 75% and 100% of subjectively-judged maximal voluntary peak force. Muscular activations were sustained for three seconds and were separated by 10 seconds of rest. The orientation of the participant and dynamometer is illustrated schematically in Figure 2.

- Insert Figure 2 here –

Assessment of musculoskeletal fitness performance.

Knee joint ligamentous performance: Index of knee laxity.

On each test occasion, assessment of anterior tibio-femoral displacement (ATFD) was undertaken in the injured and contralateral (non-injured) leg in a random order to describe knee laxity using a non-commercial laboratory instrument designed and constructed specifically to measure ATFD (Gleeson et al., 1996). The apparatus and participant orientation during assessment are shown schematically in Figure 2. The apparatus was constructed to provide an adjustable rigid chair-like framework and was designed to maintain the knee in a standardised position during the measurement of ATFD. The leg was secured by Velcro™ straps and a clamping device at the distal femur and tibia, respectively. The knee joint was maintained at 25 degrees (0.44 radians) of flexion (0 degrees [0 radians] = full extension) and foot position at 15 degrees (0.26 radians) of external rotation (19) and 20 degrees (0.35 radians) of plantar flexion. The participant was seated in an upright position with a 15 degrees (0.26 radians) angle between the back and seat supports.

Instrumentation to measure ATFD consisted of two linear inductive displacement transducers (DCT500C, RDP Electronics Ltd., Wolverhampton, U.K.: 0.025 m range). The latter incorporates spring-loaded plungers that were adjusted accurately in three planes to provide perpendicular attachment to the patella and tibial tubercle. During measurements, both transducers were secured to the skin surface using tape and able to move freely only in the anterior-posterior plane relative to the supporting framework. The instrument monitored only the relative motion between the patella and tibial sensors and so facilitated the exclusion of measurement artifacts caused by extraneous movements of the leg during the application of anterior displacement forces.

Anterior force was applied in the sagittal plane and in a perpendicular direction relative to the tibia by an instrumented force-handle incorporating a load cell (Model 31E500N0, RDP Electronics Ltd., Wolverhampton, U.K.: range 500 N). This device was positioned behind the leg at a level 0.02 m inferior to the tibial tubercle. The transducers were interfaced to a computerised data acquisition system (Cambridge Electronic Design Ltd., U.K.). Data from all transducers were sampled at 2.5 kHz.

Measurements on each knee were preceded by two practice trials. During each measurement, participants were instructed to relax the musculature of the involved limb. The latter was verified by inspection of on-line EMG records of the activity of m. biceps femoris and m. vastus lateralis. Rapid but gentle manual anterior-posterior drawer oscillations were used to facilitate relaxation and to establish a neutral tibio-femoral position from which all measurements were initiated. The same test administrator performed all measurements. Indices of ATFD were calculated as the mean of two intra-session replicates of the net displacement of the patella and tibial tubercle transducers at an anterior tibial displacement force of 160 N applied in the sagittal plane, at a rate of 67 ± 7 $N \cdot s^{-1}$ [mean ± SD]. Previous studies have shown that 160 N of applied force is associated with superior measurement reproducibility compared to lower levels of force (Gleeson et al., 1995; 1996) and is tolerated well by symptomatic participants.

The displacement transducers were calibrated against known lengths throughout the range of linear operation specified by the manufacturer (0.025 m). The standard error of the estimate associated with the recording of displacement was $\pm 1.6 \times 10^{-5}$ m. The force transducer was calibrated against known masses through a biologically valid range (0 N - 220 N) with correction for the mass of the apparatus and angle of force application. The standard error of the estimate associated with the application and recording of the applied force was ± 0.003 N. Throughout the period of testing, the calibration of the force and displacement transducers was verified against objects of known mass and length, respectively.

Maximal volitional muscle activation (MVMA)

On receipt of an auditory signal, given randomly within 1-4 seconds, the participants attempted to activate their musculature as rapidly and forcefully as possible by attempting to flex the knee joint against the immovable restraint offered by the apparatus. Another auditory signal was given to the participant after 2 - 3 seconds of MVMA to cue neuromuscular relaxation. Intra-trial MVMA replicates were each separated by at least 10 seconds to enable neuromuscular recovery (Moore and Kukulka 1991). The knee flexors were chosen for investigation as musculature that offered important contributions to the protection of the knee joint from excessive anterior tibio-femoral displacement and lateral rotation of the femur relative to the tibia but whose musculoskeletal integrity would not have been disrupted mechanically by the procedures inherent within the elective surgery that affect the capability of the knee extensors.

Peak force

Volitional static peak force (PF) was recorded as the mean response of three intra-trial replicates in which the highest force was recorded in each trial. Compensation procedures for gravitational errors in forces recorded in the vertical plane were undertaken immediately prior to testing. The average rate of force increase associated with the force-time response between 25 percent and 75 percent of peak force was calculated for each MVMA and the index of rate of force development (RFD) was described as the mean response across the replicates. Rate of force development was selected as a marker of the rate at which muscle activation can be initiated and the rapidity with which physiologically meaningful levels of force can be developed.

Electromechanical delay.

Electromyographic activity (EMG) was recorded from the m. biceps femoris during the estimation of PF. The EMG was recorded using bipolar surface electrodes (self-adhesive, silver-silver chloride, 10 mm diameter) that were applied longitudinally over the belly of m. biceps femoris, on the line between the ischial tuberosity and the lateral epicondyle of the femur. The m. biceps femoris was selected as an important contributor to restraint of anterior tibio-femoral displacement and lateral rotation of the femur relative to the tibia since both processes have been implicated in ACL injury (Fu et al., 1993).

The raw unfiltered EMG signals was passed through a differential amplifier, input impedance 10,000 MOhms, CMMR 100 dB, and a gain of 1000 (Cambridge Electronic Design,UK). The signal, which incorporated minimal intrusion from induced currents associated with external electrical and electromagnetic sources and noise inherent in the remainder of the recording instrumentation, was analogue-to-digitally converted at 2.5 kHz sample rate, ensuring a significant margin of reserve between the highest frequency expected in the EMG signal and the Nyquist frequency and minimal intrusion from aliasing errors (Gleeson, 2001). The EMG signals remained unfiltered during subsequent analyses. The inter-electrode distance was 30 mm and a reference electrode was placed 30 mm lateral and equidistant from the recording electrodes. Standardised skin preparation techniques yielded inter-electrode impedance of less than 5 kΩ.

Volitional electromechanical delay (EMD) was computed as the mean response of three intra-trial muscle activations in which the time delay between the onset of electrical activity and the onset of force was recorded. The reproducibility (coefficient of variation expressed as a percentage of the mean group score) and single measurement reliability (intra-class correlation coefficient) characteristics associated with EMD has been described previously (10.1%; 0.80; Minshull et al., 2002; Minshull et al., 2007). The onset of electrical activity was defined as the first point in time at which the electrical signal exceeded consistently the 95% confidence limits of the isoelectric line associated with the background electrical noise amplitude and quiescent muscle, and which was the first deviation of the recorded electrical signal that was congruent with physiological activation of the muscle. Onset of muscle force was defined as the first point in time at which the force record exceeded consistently the 95% confidence limits associated with the electrical noise amplitude of the load cells (please see Figure 3).

- Insert Figure 3 here –

Assessment of psychological fitness performance and rating of knee joint performance capability.

Measures of Emotional Mood State

Shortened Bi-polar Profile of Mood States (Bi-POMS). Daley and Parfitt (1994) developed this shortened version of the 72-item Bi-polar Profile Of Mood States17 using data from 293 male and female adults who completed the full 72-item scale. Six items were selected for each bi-polar subscale on the basis of factor analysis. The subscales are labelled Anxious-Composed, Hostile-Agreeable, Unsure-Confident, Confused-Clear headed, Tired-Energetic, and Depressed-Elated. Scores on each subscale range from 0 to 18 with scores approaching 0 indicating the negative mood state and scores approaching 18 indicating the positive state on each subscale. For example, a score of 0 on the Anxious-Composed subscale would indicate a highly anxious mood state, whereas a score of 18 would indicate a highly composed state. Table 1 shows a description of the feelings associated with each subscale.

Emotional Responses of Athletes to Injury Questionnaire (ERAIQ). The ERAIQ was developed on the basis of interviews with injured performers and past experiences within a sports medicine clinic (Smith et al., 1990). The form represents a structured interview format with an injured performer. The form is devised to assess the stressor itself (the injury), cognitions about the injury, the emotional response to injury, and the behaviour consequences of the injury. The emotional response to injury is assessed by three questions. Performers are asked to rate how they feel because of the injury: first, they volunteer four words in order to determine the presence of an emotional response; and second, to determine the type of response, a list of words is provided from which performers choose the four which best describe how they are feeling because of the injury. These words are helpless, tense, bored, relieved, angry, frustrated, shocked, depressed, discouraged, frightened, optimistic, in pain. Finally, the magnitude of the emotional response is measured by asking performers to rate the listed emotions by using a 5-point Likert scale of (1) absolutely not to (5) extremely so.

Emotional Profile. The emotional profile (Doyle et al., 1998) is an adaptation of the performance profile technique (Butler, 1989; Butler and Hardy, 1992) designed to measure idiosyncratic emotional responses. This emotional profile is elicited based on the individualised emotions experienced by each performer since being injured. Performers are asked to consider the question "Emotionally how have you been feeling since the injury? The exact labels listed by the performer are mapped onto a profile by the researcher. Performers complete their emotional profiles by considering the question "How are you feeling at the present time on each of the emotions you have listed? Performers record their responses by shading an area of the profile corresponding to the response scale of (1) not at all like this to (10) very much like this (see Figure 4). Performers are asked also if they perceive each of these emotions to be positive or negative for their rehabilitation. Discrepancy scores for the positive emotions are calculated by subtracting the current state score from the optimal score of 10. Discrepancy scores for the negative emotions are determined by calculating the difference between the current state score and the optimal score of 1. Standardised intra-individual and overall emotional mean discrepancy scores were calculated from all the emotions included on the profile (Sonstroem and Bernardo, 1982).

- Insert Figure 4 here –

The International Knee Documentation Committee (IKDC) Standard Evaluation Form.

The IKDC was developed by an International Committee in an attempt to provide a uniform system of evaluating the results of knee ligament injuries. The IKDC is a multi-page form that includes demographic, current health assessment and subjective knee evaluation sections. The latter includes evaluations of subjective assessment of symptoms, capability for participation in sports activities, and functionality associated with the knee joint. In the symptoms section for example, patients are asked to state the highest level at which he/she could use his/her knee without having one of the significant symptoms (for example pain, swelling, partial giving-way, and complete giving-way) even if he/she does not actually perform those activities.

Statistical analyses.

Changes in indices of musculoskeletal fitness performance.

The effect of reconstructive surgery and a subsequent early phase (2.5 months) of standardised physical rehabilitation on each index of physical fitness performance (anterior tibio-femoral displacement, peak force, and electromechanical delay) was assessed using separate two (leg: injured/non-injured) by four (time: pre-surgery, 6 wk, 8 wk, and 10 wk post-surgery) ANOVAs with repeated measures on both factors.

Changes in emotional state and knee function rating scales.

Changes in emotional state across the 4 testing occasions (pre-surgery, 6 wk, 8 wk, and 10 wk post-surgery) were compared using a single-factor ANOVA with repeated measures and post hoc Tukey HSD tests for each of the dependent variables of emotional profile score, each of the 6 Bi-POMS subscales and the 12 ERAIQ emotional responses. Because of the limited variance in IKDC scores at 6 weeks post-surgery, scores for this scale were compared using a non-parametric Friedman test across the 4 testing occasions (pre-surgery, 6 wk, 8 wk, and 10 wk post-surgery).

Relationships between indices of neuromuscular and musculoskeletal performance, emotional profile and knee function rating scales.

Correlation coefficients (Spearman rank and Pearson product-moment) were calculated between dependent variables of anterior tibio-femoral displacement, peak force, and electromechanical delay with IKDC and emotional profile scores at each of the 4 testing occasions.

A priori alpha levels were set at $p < 0.05$. The experimental design offered an approximate 0.70 power of avoiding a Type-II error when employing a least detectable difference of 0.2 mm, 16 N, 4 ms, 0.5 units and 0.3 units during comparisons of anterior tibio-femoral displacement, peak force, electromechanical delay, rate of force development, and force error, performance profile scores and IKDC scores, respectively (Lipsey, 1990).

Results

Changes in musculoskeletal fitness performance

Knee laxity: Repeated measures ANOVA showed a significant condition (injured/non-injured leg) by assessment occasion interaction for ATFD at 160 N of applied force ($F_{(3, 24)} = 6.8$; $p < .01$). Post hoc Tukey HSD tests identified a significant decrease in ATFD in the injured leg from pre-surgery to 6 weeks, 8 weeks, and 10 weeks post-surgery (9.6 ± 2.2 mm, 6.4 ± 1.8 mm and 6.8 ± 1.7 mm vs. 7.4 ± 2.3 mm, respectively; please see figure 5). The ATFD remained constant in the non-injured, contralateral control leg. The injured leg had significantly greater ATFD pre-surgery compared to the non-injured leg and at 8 weeks post-surgery compared to the non-injured leg. Thus the maximum extent of the relative effect ([mean score post-surgery – mean score pre-surgery]/pooled standard deviation) of the surgical intervention and subsequent acute physical exercise conditioning represented a 1.8-fold increase in musculoskeletal fitness performance capability.

- Insert Figure 5 here –

Peak force; electromechanical delay. Factorial ANOVAs with repeated measures showed a significant leg (injured/non-injured) by time (pre-surgery, 6 weeks, 8 weeks, and 10 weeks post-surgery) for peak force and electromechanical delay ($F_{(3,\ 24)}$ = 7.3 to 16.5; $p < 0.01$). Whereas neuromuscular fitness performance remained constant throughout the period of assessment in the non-injured leg, post hoc Tukey HSD tests identified significant decreases in peak force at 6 weeks post-surgery (159 ± 35 N vs. 194 ± 38 N, respectively; see figure 6) compared to pre-surgery performance fitness levels in the injured leg. A significant progressive increase in performance of electromechanical delay was noted between pre-surgery performance fitness levels and performance capabilities at 10 weeks post-surgery in the injured leg (74 ± 17 ms, 59 ± 16 ms, 46 ± 17 ms and 45 ± 15 ms, respectively; see figure 7). The maximum relative effect size of 1.1 and 1.8 for the influence of the surgical intervention and subsequent acute physical exercise conditioning on peak force and electromechanical delay, respectively, represented substantial changes in physical fitness performance capabilities compared to pre-surgery levels.

- Insert Figures 6 and 7 here –

Changes in measures of emotional response

Group mean scores for emotional profile mean profile discrepancy scores, the Bi-POMS subscales (tired-energetic, depressed-elated, confused-clearheaded, anxious-composed, hostile-agreeable, unsure-confident) and the ERAIQ emotional responses (helpless, tense, bored, discouraged, frustrated, shocked, depressed, in pain, angry, frightened, optimistic and relieved) at pre-surgery, 6 weeks post-surgery, 8 weeks post-surgery and 10 weeks post-surgery are shown in Table 2.

Emotional profile. Repeated measures ANOVA showed significant differences in mean profile discrepancy scores across the 4 assessment occasions ($F_{(3,24)}$ = 7.9; $p < 0.01$). Post hoc Tukey HSD tests indicated that discrepancy scores were significantly less at 10 weeks post-surgery compared to pre-surgery, 6 weeks post-surgery, and 8 weeks post-surgery (see figure 8). These results show a reduction in emotional disturbance scores across the later stages of the experimental period. The maximum extent of the relative effect of the surgical intervention and subsequent acute physical exercise conditioning showed a substantial 3.2-fold change in self-perception of emotional status.

- Insert Figure 8 here –

Shortened Bi-polar Profile of Mood States. Results from ANOVA with repeated measures showed significant differences in the Bi-POMS depressed-elated subscale scores across the 4 assessment occasions ($F_{(3,24)} = 9.8$; $p < 0.01$). Post hoc Tukey HSD tests indicated significantly greater depressed-related subscale scores at 8 weeks post-surgery and 10 weeks post-surgery compared to pre-surgery scores. Significant differences in the Bi-POMS confused-clearheaded subscale scores across the 4 assessment occasions were also noted ($F_{(3,24)} = 3.6$; $p < 0.05$), with follow-up tests indicating significantly lower confused-clearheaded subscale scores at 6 weeks post-surgery compared to pre-surgery scores (see figure 9). Further analyses showed significant differences in the Bi-POMS anxious-composed and hostile-agreeable subscale scores across the 4 assessment occasions ($F_{(3,24)} = 4.5$; $p < 0.01$ and $F_{(3,24)} = 4.2$; $p < 0.05$, respectively). Post hoc Tukey HSD tests indicated significantly lower anxious-composed subscale scores at 6 weeks post-surgery compared to pre-surgery scores (see figure 10) and significantly higher hostile-agreeable subscale scores at 8 weeks post-surgery compared to 6 weeks post-surgery. No significant differences were noted in Bi-POMS subscales scores for tired-energetic scale and the unsure-confident scale across the 4 assessment occasions. In general these results suggested that performers became less depressed and more elated, and less hostile and more agreeable, as they progressed across the experimental period. They also show that performers became more anxious and less composed, and more confused and less clearheaded, across the initial stages of the experimental period. The significant sub-scale changes were characterised by maximum relative effect sizes ranging from 0.6 to 1.7 for the influence of the surgical intervention and subsequent acute physical exercise conditioning.

- Insert Figure 9 & 10 here –

Emotional responses of athletes to injury questionnaire. Results from ANOVA with repeated measures showed significant differences in the ERAIQ emotional response of helpless across the 4 assessment occasions ($F_{(3,24)} = 7.4$; $p < 0.01$). Post hoc Tukey HSD tests indicated significantly lower scores at 6 weeks post-surgery, 8 weeks post-surgery and 10 weeks post-surgery compared to pre-surgery scores. Similarly, results showed significant differences in the ERAIQ emotional responses of bored and frustrated across the 4 assessment occasions ($F_{(3,24)} = 3.9$; $p < 0.05$ and $F_{(3,24)} = 2.9$; $p < 0.05$, respectively). Post hoc HSD Tukey tests indicated significantly lower boredom scores at 10 weeks post-surgery compared to pre-surgery scores and significantly lower frustration scores at 8 weeks post-surgery compared to 6 weeks post-surgery scores. Furthermore, results showed significant differences in the ERAIQ emotional response of angry across the 4 assessment occasions ($F_{(3,24)} = 5.5$; $p < 0.01$), with follow-up tests indicating significantly lower scores at 6 weeks post-surgery, 8 weeks post-surgery and 10 weeks post-surgery compared to pre-surgery scores (see figure 11). No significant differences in ERAIQ emotional responses of tense, shocked, depressed, in pain, frightened, optimistic and relieved across the 4 assessment occasions.

These results suggest that performers became less helpless, bored, frustrated and angry as they progressed across the experimental period. The maximum relative effect size of up to 1.6 for the influence of the surgical intervention and subsequent acute physical exercise conditioning on the ERAIQ emotional responses that showed statistically significant changes, was substantive.

- Insert Figure 11 here –

International Knee Documentation Committee Form.

A non-parametric Friedman test showed no significant differences in IKDC scores across the 4 assessment occasions ($F_{(3, 24)} = 1.5$; $p > .05$). These results suggest that IKDC scores did not change across the experimental period.

Relationships between indices of neuromuscular and musculoskeletal performance, emotional profile and knee function rating scales.

Emotional profile. Spearman rank correlation coefficients showed significant relationships between standardised emotional mean profile discrepancy scores and anterior tibio-femoral displacement, peak force and electromechanical delay scores ($r_s = 0.68$; $p < 0.05$; $r_s = 0.85$; $p < 0.01$; $r_s = -0.82$; $p < 0.01$, respectively) pre-surgery. A significant relationship was also found between standardised emotional mean profile discrepancy scores and anterior tibio-femoral displacement, peak force and electromechanical delay scores ($r_s = 0.72$; $p < 0.05$; $r_s = 0.82$; $p < 0.01$; $r_s = -0.81$; $p < 0.01$, respectively) at 8 and anterior tibio-femoral displacement and electromechanical delay ($r_s = 0.70$; $p < 0.05$; $r_s = -0.84$; $p < 0.01$, respectively) at 10 weeks post-surgery.

Emotional responses of athletes to injury questionnaire. Spearman rank correlation coefficients showed significant relationships between ERAIQ discouraged scores and anterior tibio-femoral displacement ($r_s = 0.79$; $p < 0.05$) and peak force ($r_s = 0.75$; $p < 0.05$) scores pre-surgery. Analyses showed a significant relationship between ERAIQ in pain scores and ATFD scores ($r = 0.78$; $p < 0.05$) at 10 weeks post-surgery. No significant relationships were found between the ERAIQ responses of helpless, tense, bored, frustrated, shocked, depressed, optimistic, angry, frightened, relieved, and ATFD at each of the 4 assessment occasions.

Shortened Bi-polar profile of Mood States. Significant relationships were found between the Bi-POMS tired-energetic subscale scores and anterior tibio-femoral displacement scores ($r = -0.87$; $p < 0.01$) at 8 weeks post-surgery. Analyses revealed significant relationships between the Bi-POMS depressed-elated subscale scores and anterior tibio-femoral displacement scores ($r = -0.85$; $p < 0.01$) and electromechanical delay scores ($r = - 0.77$; $p < 0.05$) at 8 weeks post-surgery and between the Bi-POMS confused-clearheaded subscale scores and peak force at 8 weeks post-surgery ($r = 0.72$; $p < 0.05$) and at 10 weeks post-surgery ($r = 0.74$; $p < 0.05$). Further analyses revealed significant relationships between the Bi-POMS anxious-composed subscale scores and peak force scores ($r = 0.77$; $p < 0.05$) and between the Bi-POMS hostile-agreeable subscale scores and anterior tibio-femoral displacement scores ($r = -0.72$; $p < 0.05$) at 8 weeks post-surgery.

International Knee Documentation Committee Form. Correlation coefficients showed no significant relationships between the dependent variables of physical performance with IKDC and emotional profile scores at each of the 4 assessment occasions.

Rehabilitation diary.

The group mean number of weekly rehabilitation sessions and the group mean weekly rehabilitation times are shown in Table 1. The clinical rehabilitation programme showed heterogeneity in the amount of rehabilitation performed.

Discussion

Musculoskeletal fitness and the emotional profile.

Over the assessment period, anterior tibio-femoral displacement scores for the non-injured control leg were maintained at pre-intervention levels. The ATFD scores in the injured leg were significantly less at 6, 8 and 10 weeks post-surgery compared to pre-surgery levels. Group mean scores showed a 27% decrease in ATFD scores in the injured leg from pre-surgery to 10 weeks post-surgery. At 6 weeks post-surgery there were no significant differences in ATFD scores between legs providing support for the immediate success of surgery to re-establish a ligamentous stabilisation in the knee joint. However, ATFD scores were significantly greater in the injured leg than the non-injured leg at 8 weeks post-surgery. These results may potentially indicate a stretching of the new ligament in response to the increased physiological stress of the rehabilitation programme at 6 weeks post-surgery. Although this trend is contrary to the documented changes shown in conventional clinical literature, similar trends had been reported elsewhere (Gleeson et al, 2005).

Furthermore, whereas neuromuscular fitness performance in the non-injured leg remained constant throughout the period of assessment, significant decreases in peak force at 6 weeks post-surgery (19%) compared to pre-surgery performance fitness levels were shown in the injured leg. In contrast, a significant progressive increase in electromechanical delay was noted between pre-surgery performance fitness levels and performance capabilities at 6, 8, and 10 weeks post-surgery in the injured leg (i.e. 21%, 36% and 40% reductions in EMD, respectively) (Minshull et al., 2007). These findings for musculoskeletal fitness performance confirm that the surgical and physical therapeutic intervention design employed in this study provided a period of dramatic change in the physical fitness capabilities of this injured population. Alongside the large percentage changes in fitness performance of between 19% and 40% compared to baseline, the extent of change in musculoskeletal and neuromuscular performance capability is also illustrated by the large relative effect sizes of between 0.6 and

1.8. This period of change thus provides a useful environment in which to assess the responsiveness of the performance profile technique and other measures of knee function (Gleeson et al., 2005; Doyle et al., 1998).

Group mean scores for the emotional profile showed that this measure was sensitive to the dramatic change in physical performance reported over the assessment period. Standardised mean emotional profile discrepancy scores showed that performers had significantly less emotional disturbance at 10 weeks post-surgery compared to pre-surgery, 6 weeks and 8 weeks post-surgery. This reduction in emotional disturbance is congruent with the patterns of physical performance across this period giving some initial support for the validity of the emotional profile technique in this population. It was interesting to note that while the standardised emotional profile discrepancy scores appeared to be congruent with aspects of the patterning of dramatic changes in musculoskeletal performance capability across the experimental period, the responses tended to scale to above the overall extent of change in the latter markers of fitness performance (maximum relative effect size of 3.2 vs. 0.6 to 1.8, respectively).

Thus compared to the extent of improvements in physical fitness and when assessed using an individualised tool, self-perception of emotional status was amplified but congruent with the patterns of change in physical performance during the period of conditioning. The amplification of the scaling of emotional responses to changes in physical fitness was not evident in those from either the emotional responses of athletes to injury or the shortened bi-polar profile of mood states questionnaires. It is plausible that the amplification of response is precise and a feature of the process of individualisation within the assessment.

Alternatively, since participants on average had been injured 20.4 months prior to surgery, it could be argued that over this time period participants had limited experience of stressing or testing the injured knee joint and had become habituated to the feel of the injured leg. This type of compensation effect may have led to inaccurate scaling of emotional response and to over-estimation in the perceived effect of surgery and initial phase of rehabilitation conditioning. Additionally, substantial deconditioning of both the injured and the non-injured legs prior to surgery may have contributed to an over-compensation of emotional response to the relatively dramatic changes in musculoskeletal fitness performance during rehabilitation.

It was also plausible that the increase in self-perceived emotional response during the initial phases of rehabilitation may have been a reflection of the characteristics of the early stages of the rehabilitation process. The rehabilitation is designed to be very protective of the healing bone graft and avoids substantial stretching of the tissue initially. Thus, over this period contraction of the quadriceps muscle is avoided. This conservative rehabilitation may have led to ineffective pychophysiological scaling and to participants perceiving greater dysfunction in their knees compared to pre-surgery levels. It may be that over this initial period, emotional profile discrepancy scores may better reflect changes in quadriceps strength. An alternative explanation is that the invasive reconstructive surgery and the traumatic early stages of rehabilitation may make accurate scaling of emotions difficult at this stage of the rehabilitation p scaling rocess.

Correlation measures between standardised mean emotional profile discrepancy scores and the musculoskeletal fitness scores were employed at each assessment occasion to further assess the potential linkages with disturbances to emotional fitness status. These analyses also provided support for the construct validity of a pychophysiological approach to the assessment of fitness during rehabilitation conditioning. Specifically, higher emotional disturbance was related to higher anterior tibio-femoral displacement (i.e. greater knee laxity and ligamentous compliance), muscular weakness and longer muscle activation delays at pre-surgery and at 8 weeks post-surgery. These results offered further support for the sensitivity of the emotional profile technique during the early stages of rehabilitation.

Overall, the pattern and extent of changes in the emotional performance profile discrepancy scores in conjunction with those from indices of musculoskeletal performance capability give some support for the validity of a pychophysiological approach to the assessment of fitness capability during rehabilitation following surgery to a synovial joint. Emotional discrepancy scores were generally congruent with changes in musculoskeletal performance capability at all stages of the experimental period and may be considered to be a useful adjunct to the assessment of improvements to physical fitness during recovery.

Utility of ERAIQ and Bi-POMS inventories.

The ERAIQ has been one of the most prevalent inventories for the assessment of emotional responses in injured performers. Of the 12 emotional responses included in the injured specific ERAIQ , only 4 were sensitive to the physical changes over the assessment period (helpless, bored, frustrated, angry). These results showed gradually less emotional disturbance as performers progressed through rehabilitation. As was alluded to earlier, the relative effect sizes of ERAIQ-derived changes in emotional status were reduced compared to those associated with the emotional profile (maximum relative effect size of 3.2 vs. 1.6, respectively). However, 8 of the 12 ERAIQ emotional responses were not sensitive to the changes in physical measures over the assessment period. This raised some concerns over the validity of the emotional responses included within the ERAIQ. Results from correlation analyses also provided limited support for all the responses included in the ERAIQ. Sporadic relationships were found between the emotional responses included on the ERAIQ and the physical performance measure across the 4 test occasions. LaMott (1996) had shown previously that only the responses of anger, frustration and pain were significantly related to physical recovery, measured by range of motion, following ACL-reconstructive surgery.

In contrast to the emotional profile and ERAIQ responses, the Bi-POMS showed inconsistent patterns of emotional responses across the assessment period. The depressed-elated subscale followed a similar pattern of response as the emotional profile, ERAIQ and the physical measure. However, the confused-clearheaded subscale followed an unexpected pattern and showed that performers were significantly more confused and less clearheaded at 6 weeks post-surgery compared to pre-surgery. Similarly, results showed that performers were significantly more anxious and less composed at 6 weeks post-surgery compared to pre-surgery levels. These inconsistent findings are also highlighted through correlation analyses. Analyses revealed that at 8 and 10 weeks post-surgery lower anterior tibio-femoral displacement scores and improved strength and muscular activation times were associated with a more confused and less clearheaded emotional state. Similarly, at 8 weeks post-surgery lower anterior tibio-femoral displacement scores were associated with a more anxious and less composed emotional state. These findings raise concern over the validity of the Bi-POMS to assess changes in emotional response in this population during this specific phase of rehabilitation.

Furthermore, while the IKDC form has become the ‘gold standard’ knee rating scale in conventional clinical practice, results showed that this scale was not sensitive to the large pychophysiological changes across the surgical and rehabilitative period. Additionally, correlation analyses did not identify any significant relationships between the IKDC and indices of musculoskeletal performance capability across the 4 assessment occasions. These results are in contrast to the findings of Mayor et al. (1996), who found that the IKDC was sensitive to variations in postoperative measures of stability. These findings resonate with recent concerns about the uncorroborated use of subjective ratings of knee joint performance (Zarins, 2005) and highlight some concerns over the validity of rating scales used in contemporary clinical practice.

Functional implications and conclusions.

Results indicated significant improvements in the physical measure of ligamentous integrity and musculoskeletal fitness from pre-surgery to 6 weeks post-surgery. In general, levels of emotional disturbance did not significantly decrease from pre-surgery levels until after this initial 6-week period. These results suggest that this initial period of rehabilitation following surgery provides a substantial threat to the psychological well-being of the performer. These findings have important implications for clinical practitioners. It could be argued that psychological interventions and coping strategies designed to improve patients' psychological well-being may be most needed and have greatest effectiveness during this period. Furthermore, the physiotherapist should be aware that performers are likely to experience high levels of emotional disturbance and perceive high levels of dysfunction over this period.

Overall, the pattern and extent of changes in the emotional performance profile discrepancy scores in conjunction with those from indices of musculoskeletal performance capability give some support for the validity of a pychophysiological approach to the assessment of fitness capability during rehabilitation following surgery to a synovial joint. The results suggest that this inventory may provide practitioners with a useful individualised visual measure of emotional state that also may reflect changes in physical recovery across the rehabilitation period. Analyses of other measures of emotional responses highlighted concerns over the validity of the Bi-POMS to assess changes in emotional response in this population during this phase of rehabilitation.

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Table 1. Shortened Bi-polar Profile of Mood States subscales (associated items/feelings on questionnaire).

Anxious *(anxious, nervous, uneasy)* - **Composed** *(composed, peaceful, untroubled)*
Hostile *(annoyed, bad tempered, grouchy)* - **Agreeable** *(good-natured, kindly, friendly)*
Unsure *(inadequate, unsure, uncertain)* - **Confident** *(self-assured, powerful, confident)*
Confused *(muddled, dazed, perplexed)* - **Clear headed** *(efficient, able to concentrate)*
Tired *(sluggish, weary, fatigued)* - **Energetic** *(active, energetic, ready to go)*
Depressed *(discouraged, downhearted gloomy)* - **Elated** *(light-hearted, jolly, joyful)*

Table 2. Group mean scores (SD) for standardised emotional profile mean profile discrepancy scores, the Bi-POMS subscales (tired-energetic, depressed-elated, confused-clearheaded, anxious-composed, hostile-agreeable, unsure-confident) and the ERAIQ emotional responses (helpless, tense, bored, discouraged, frustrated, shocked, depressed, in pain, angry, frightened, optimistic and relieved) at pre-surgery, 6 weeks post-surgery, 8 weeks post-surgery and 10 weeks post-surgery.

	TIME			
Inventory	pre-	6 wks post-	8 wks post-	10 wks post-surgery
EMOTIONAL PROFILE	0.63 (0.62)	0.91 (1.39)	0.27 (1.01)	-1.81 (1.28)
POMS				
tired-energetic	11.6 (5.1)	8.8 (2.8)	10.1 (2.9)	10.1 (3.6)
depressed-elated	8.8 (5.0)	11.3 (2.9)	13.4 (3.9)	13.2 (3.6)
confused-clearheaded	14.8 (2.4)	12.1 (2.8)	14.7 (2.5)	14.7 (3.3)
anxious-composed	9.2 (4.5)	11.7 (2.8)	13.0 (3.9)	13.8 (3.1)
hostile-agreeable	11.8 (4.2)	11.6 (2.5)	14.9 (4.0)	14.6 (3.6)
unsure-confident	10.7 (4.1)	8.6 (3.8)	12.0 (3.6)	12.2 (4.0)
ERAIQ				
helpless	3.56 (1.59)	2.56 (1.42)	1.78 (1.09)	2.11 (0.93)
tense	2.67 (1.41)	2.67 (1.41)	2.22 (1.20)	2.00 (1.00)
bored	3.33 (1.73)	3.22 (1.09)	2.44 (1.24)	2.00 (1.41)
discouraged	2.89 (1.62)	2.33 (1.22)	1.67 (0.71)	2.11 (1.27)
frustrated	4.00 (1.41)	4.11 (1.05)	3.00 (1.50)	3.33 (1.32)
shocked	2.22 (1.30)	1.78 (1.09)	1.22 (0.67)	1.56 (0.88)
depressed	3.00 (1.50)	2.44 (1.13)	2.11 (1.54)	1.67 (1.12)
in pain	2.56 (1.24)	2.56 (1.24)	2.33 (1.41)	2.56 (0.88)
angry	2.67 (1.50)	1.56 (0.73)	1.44 (0.73)	1.56 (0.73)
frightened	2.00 (1.12)	1.33 (0.50)	1.56 (1.33)	1.56 (0.88)
optimistic	3.22 (1.20)	3.67 (1.41)	3.78 (0.83)	3.44 (1.13)
relieved	2.89 (1.54)	3.33 (1.32)	3.56 (1.01)	3.22 (0.83)

Week seven	10.67 (5.22)	473.3 (257.7)
Week eight	10.22 (5.72)	436.1 (253.8)
Week nine	7.78 (4.15)	293.9 (166.0)
Week ten	9.44 (5.39)	421.1 (212.8)

Table 3 Group mean (SD) number of rehabilitation sessions and the group mean rehabilitation time (SD) for week 1 to week 10 post-surgery.

	Number of Sessions *Mean (SD)*	*Total Time (mins)* *Mean (SD)*
Week one	13.78 (9.15)	402.8 (184.8)
Week two	17.33 (11.84)	402.2 (150.7)
Week three	17.89 (10.94)	448.3 (181.7)
Week four	16.00 (7.58)	448.9 (224.9)
Week five	14.00 (7.28)	385.6 (189.9)
Week six	12.56 (6.54)	413.3 (229.1)
Week seven	10.67 (5.22)	473.3 (257.7)
Week eight	10.22 (5.72)	436.1 (253.8)
Week nine	7.78 (4.15)	293.9 (166.0)
Week ten	9.44 (5.39)	421.1 (212.8)

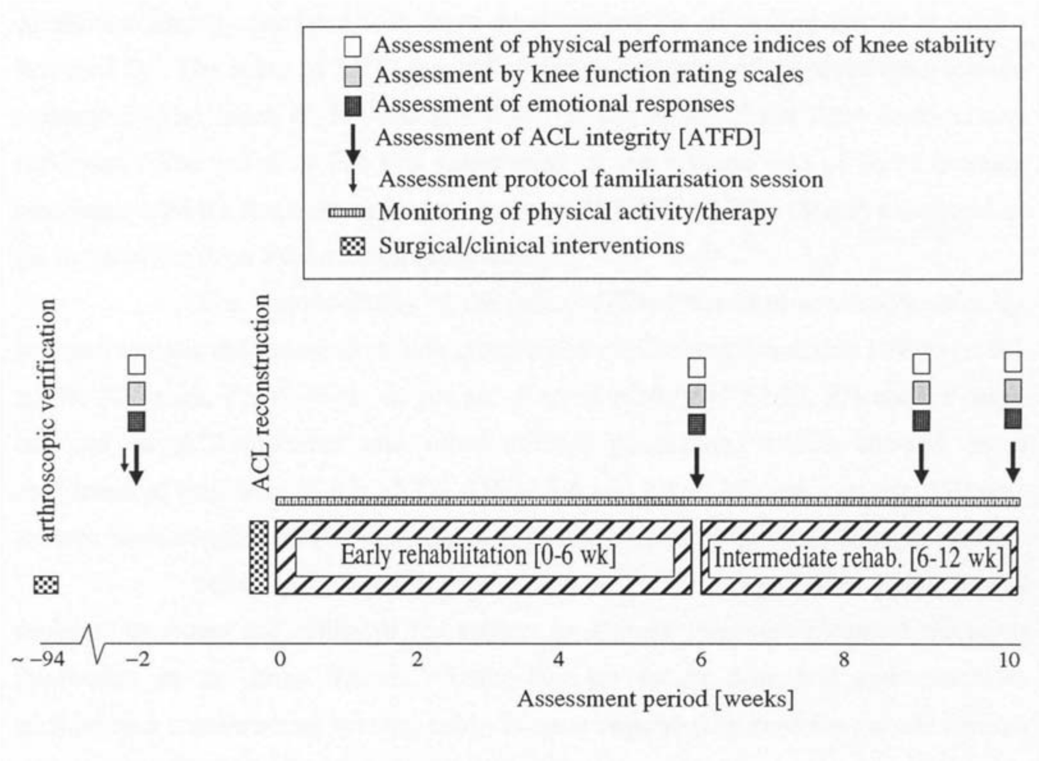

Figure 1. Schematic of the assessment protocol associated with surgical reconstruction of the ACL (bone-patella tendon-bone graft) and subsequent postoperative physical rehabilitation conditioning.

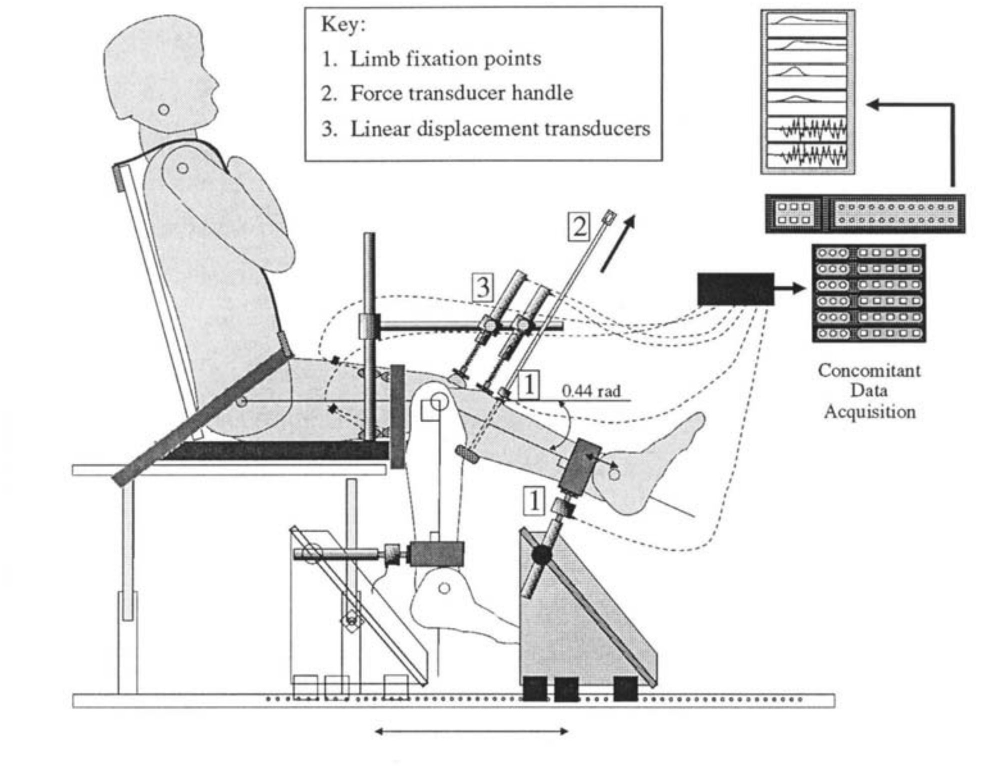

Figure 2. Participant and integrated measurement system for the assessment of anterior tibio-femoral displacement (ATFD) and associated indices of neuromuscular knee joint performance.

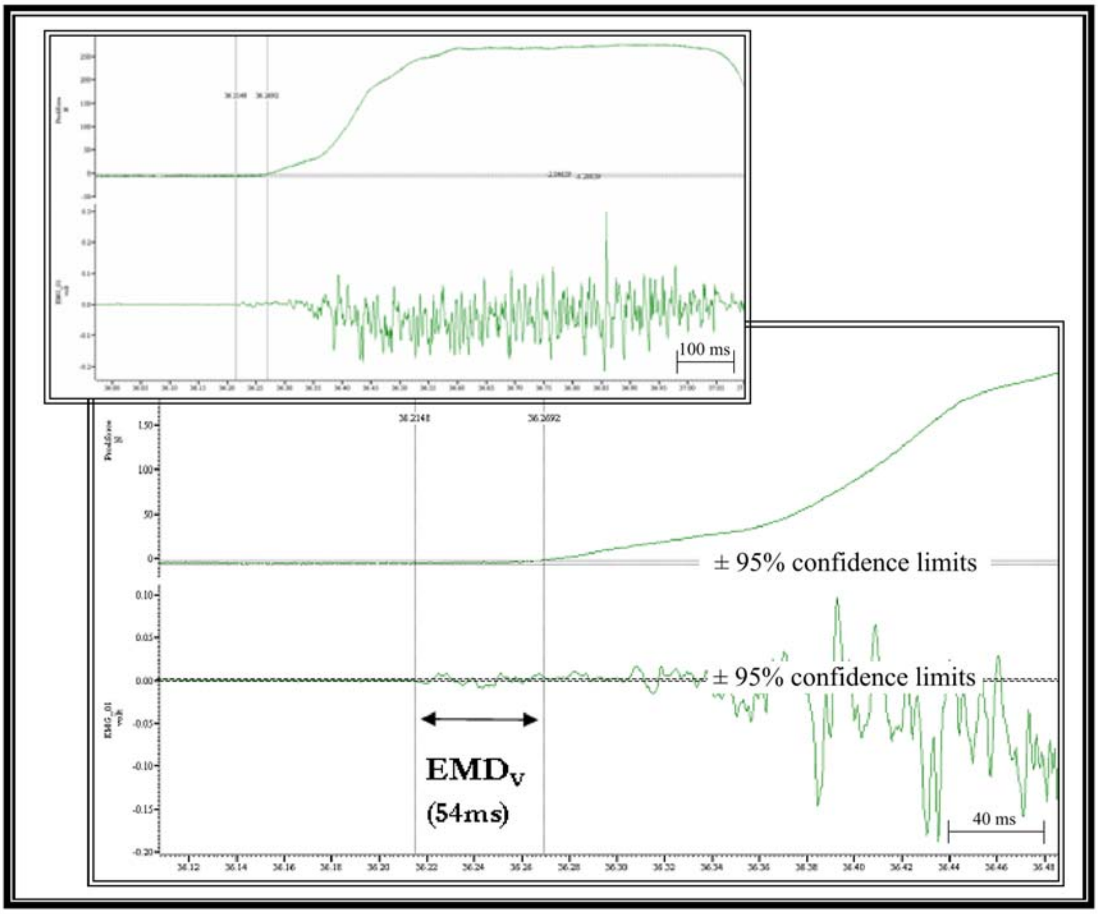

Figure 3. Example raw data showing: upper trace: example data of force and EMG associated with one maximal voluntary muscle activation; lower trace: magnification of muscle activation to show representative calculation of volitional electromechanical delay (EMD).

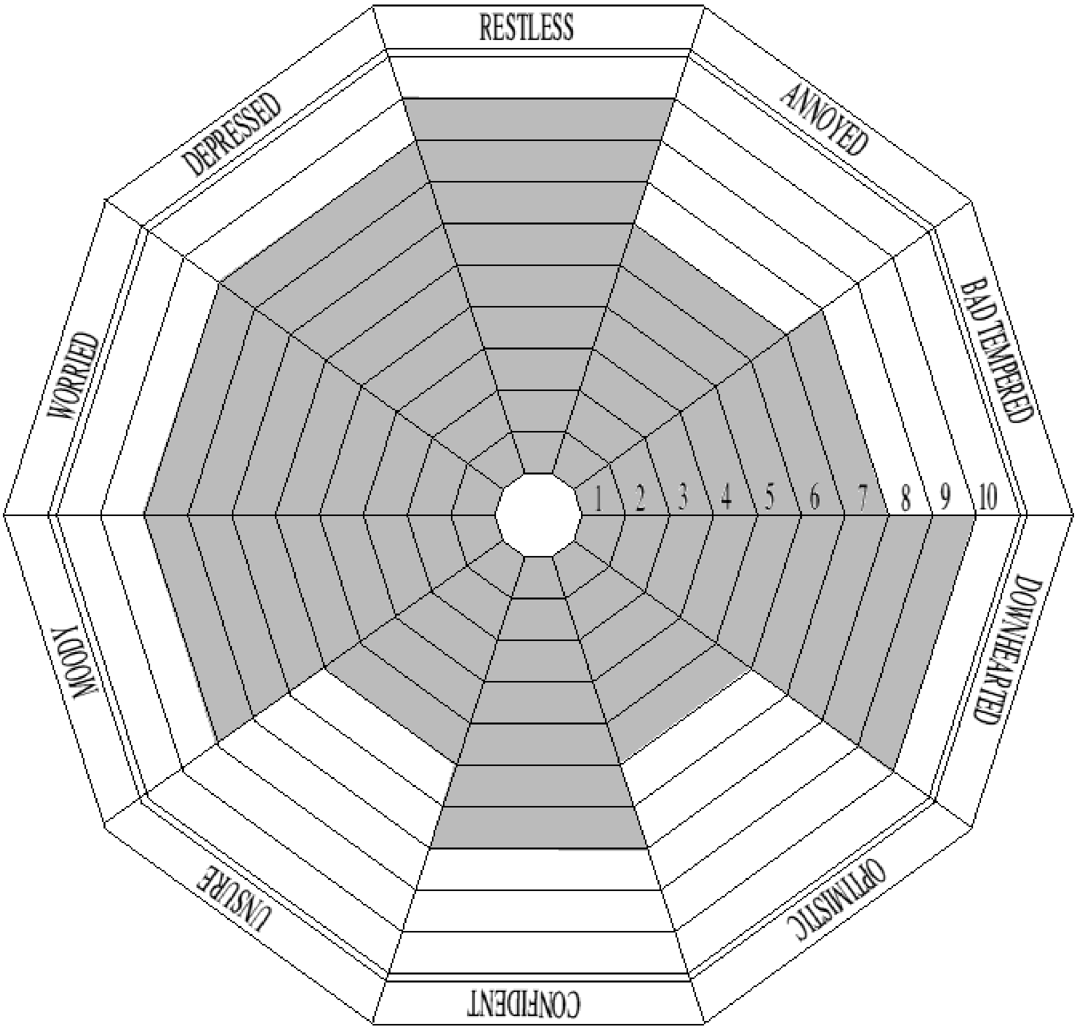

Figure 4. Completed emotional profile with the emotions the performer has experienced since the injury displayed around the perimeter of the profile. The shaded area represents the perceived current state on each of these emotions (response scale : (1) not at all like this to (10) very much like this).

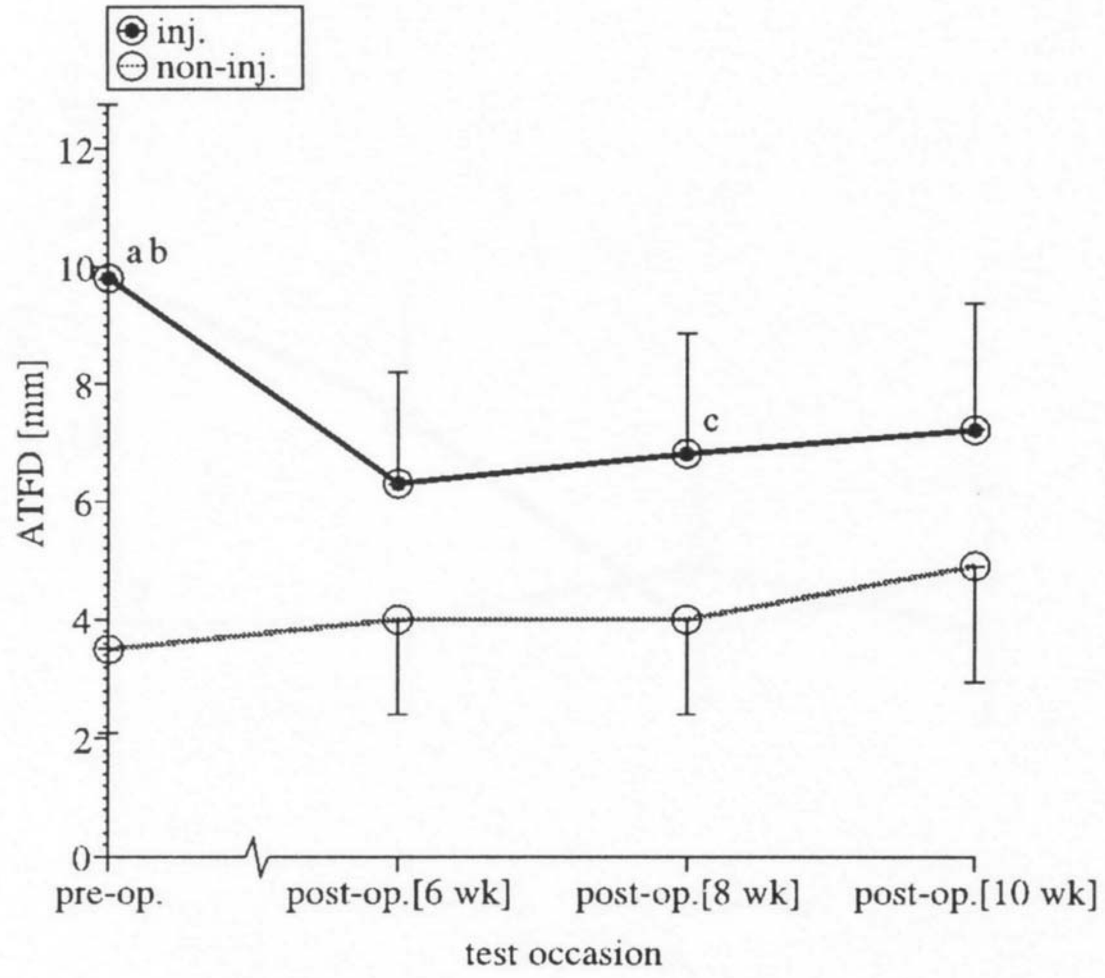

Figure 5. Group mean (SD) anterior tibio-femoral displacement (ATFD) scores [mm] for injured and non-injured leg conditions (n = 9). Assessments are pre-operation and 6 wk, 8 wk and 10 wk post-operation. (a) significant decrease in ATFD in the injured leg from pre-surgery to 6 weeks, 8 weeks, and 10 weeks post-surgery ($p < 0.01$).

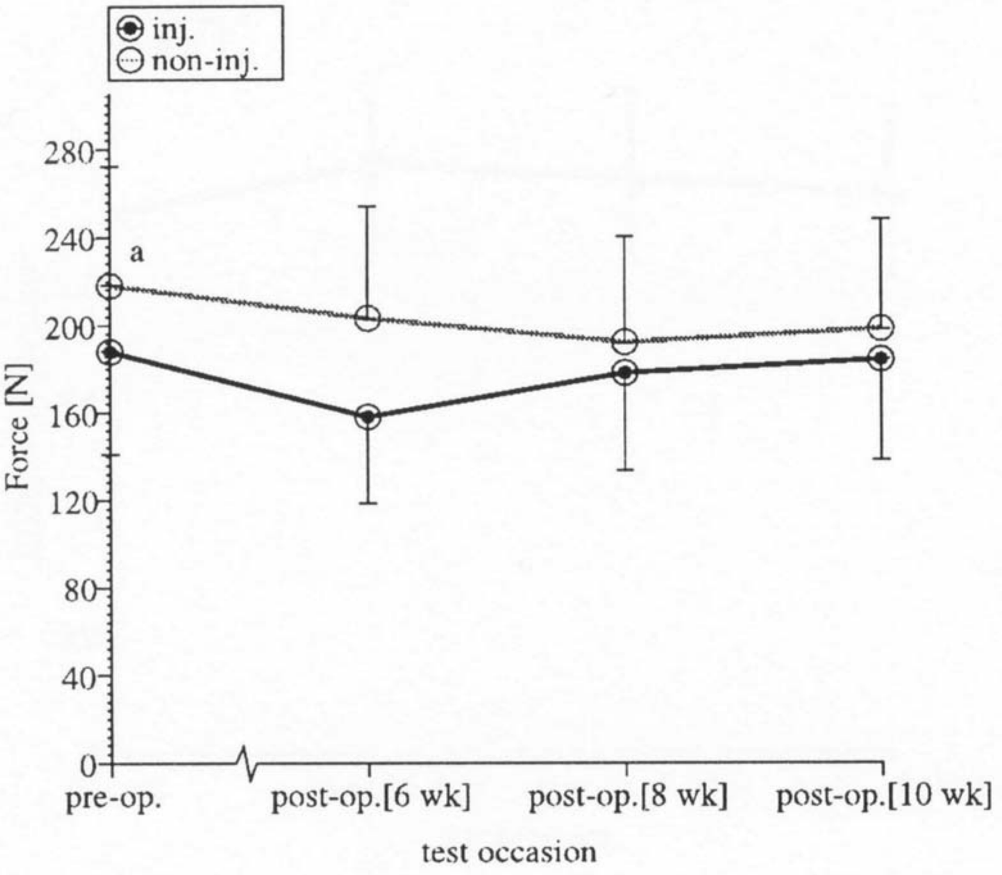

Figure 6. Group mean peak force (n = 9) associated with knee flexion for injured and non-injured legs at 0.44 rad of knee flexion. Assessments are pre-operation and 6 wk, 8 wk and 10 wk post-operation. Data are mean ± SD. (a) decreases in peak force at 6 weeks post-surgery compared to pre-surgery performance in the injured leg ($p < 0.01$).

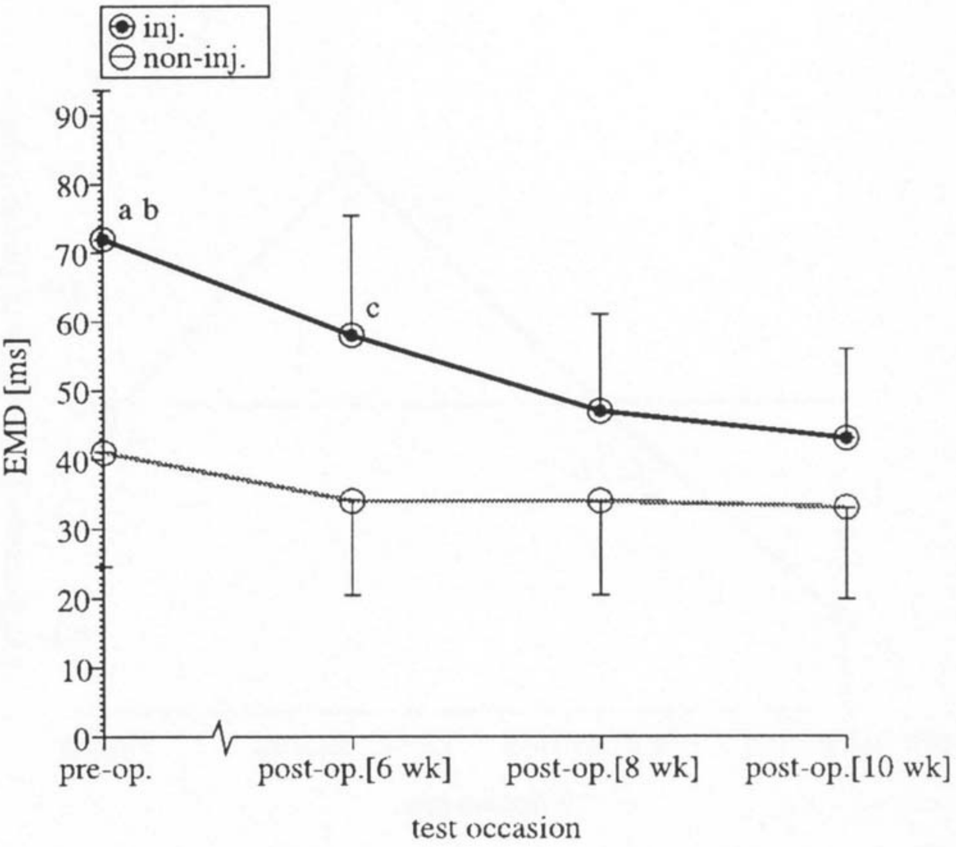

Figure 7. Group mean electromechanical delay (EMD) [m. biceps femoris; ms] (n = 9) associated with knee flexion for injured and non-injured legs at 0.44 rad of knee flexion. Assessments are pre-operation and 6 wk, 8 wk and 10 wk post-operation. Data are mean ± SD. (a) progressive increase in performance of electromechanical delay was noted between pre-surgery performance fitness levels and performance capabilities at 10 weeks post-surgery in the injured leg ($p < 0.01$).

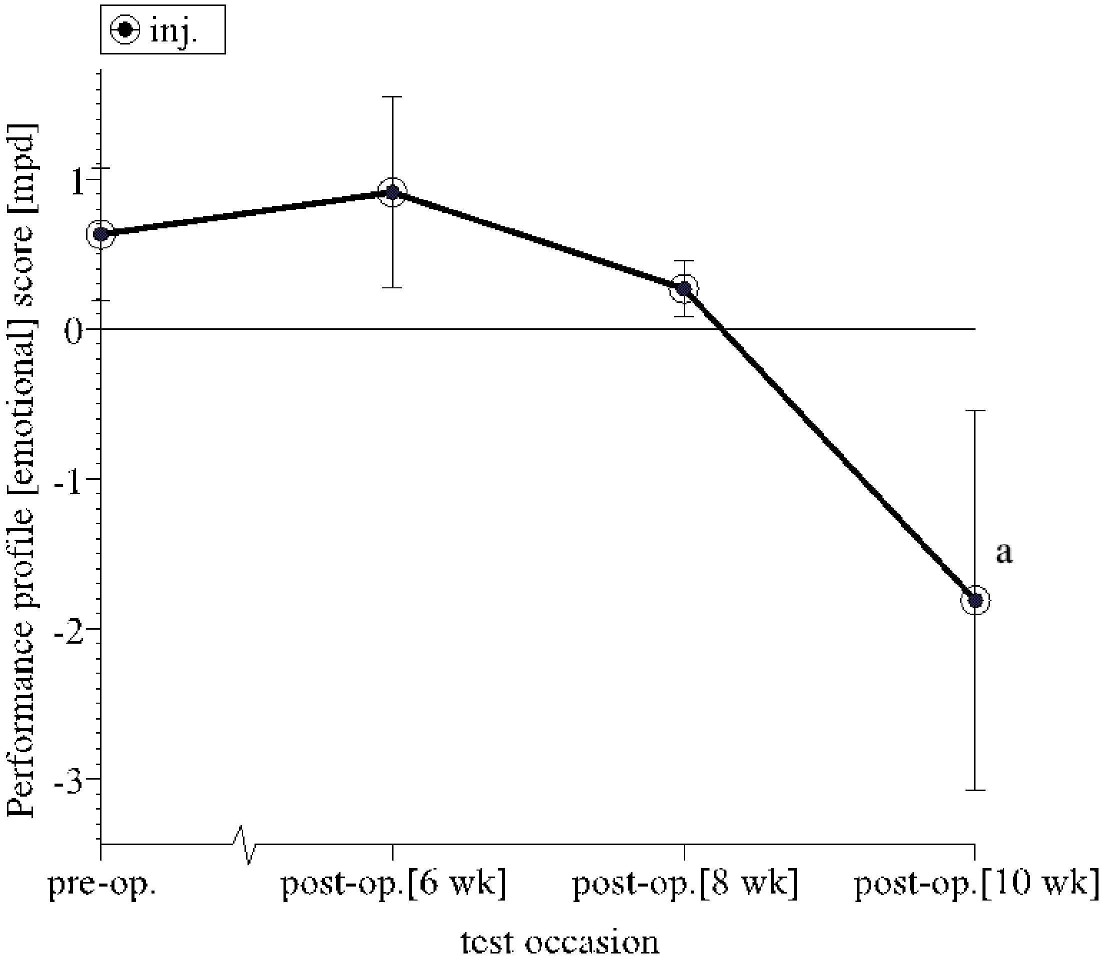

Figure 8. Group mean emotional profile score (mean profile discrepancy score) for injured leg condition (n = 9). Assessments at pre-surgery and 6 wk, 8 wk, and 10 wk post-surgery. Data are mean and SD. (a) Post-surgery (10 wk) < pre-surgery; post-surgery (6 wk); post-surgery (8 wk) ($p < 0.05$).

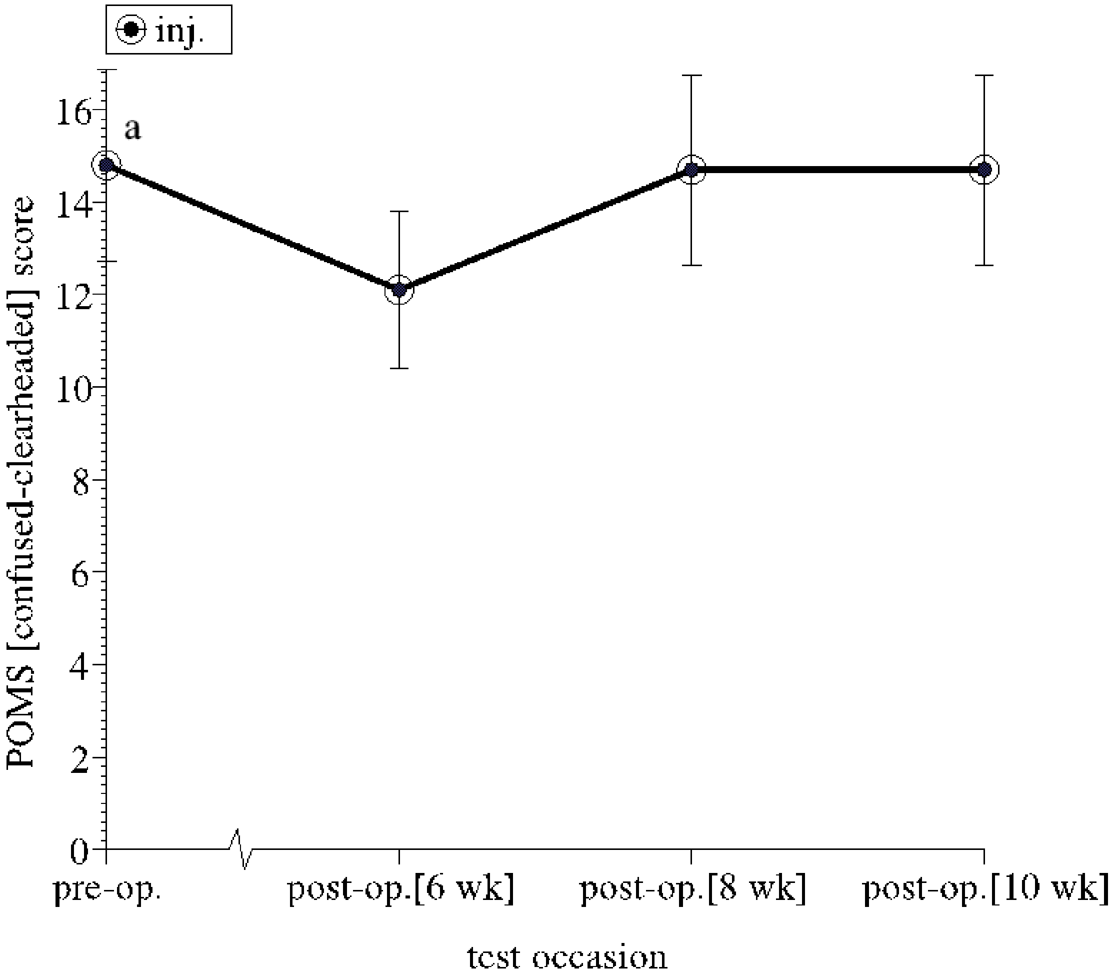

Figure 9. Group mean Bi-POMS score (confused-clearheaded subscale) for injured leg condition (n = 9). Assessments at pre-surgery and 6 wk, 8 wk, and 10 wk post-surgery. Data are mean and SD. (a) Pre-surgery > post-surgery (6 wk) ($p < 0.05$).

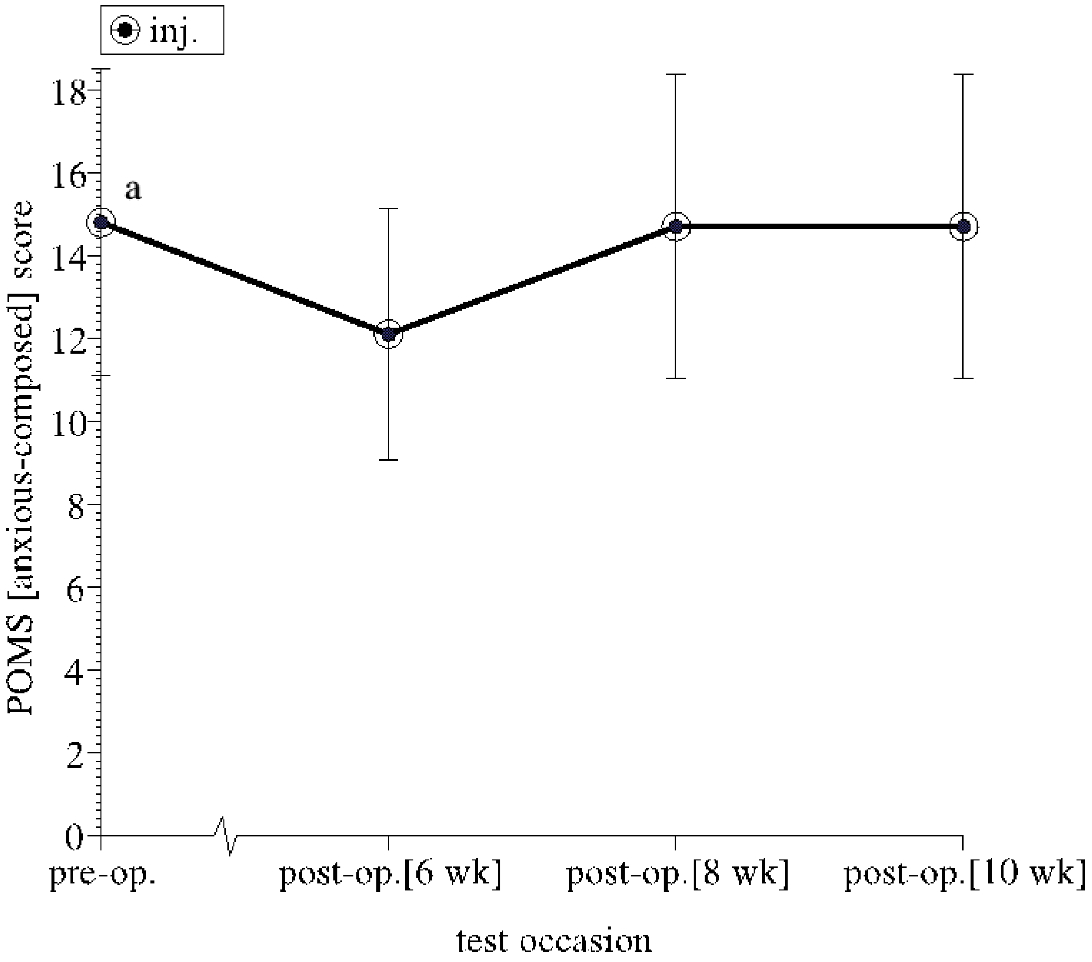

Figure 10. Group mean Bi-POMS score (anxious-composed subscale) for injured leg condition (n = 9). Assessments at pre-surgery and 6 wk, 8 wk, and 10 wk post-surgery. Data are mean and SD. (a) Pre-surgery > post-surgery (6 wk) ($p < 0.05$).

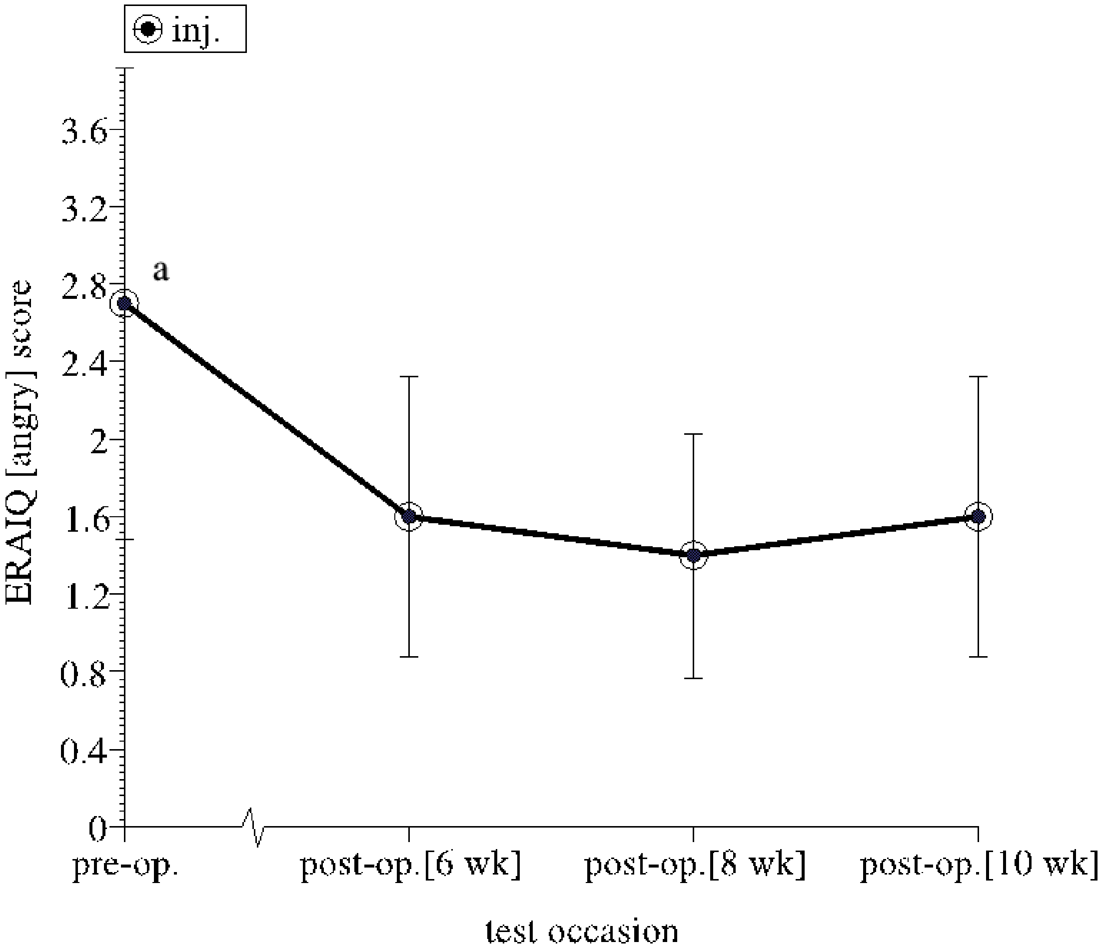

Figure 11. Group mean ERAIQ score (angry subscale) for injured leg condition (n = 9). Assessments at pre-surgery and 6 wk, 8 wk, and 10 wk post-surgery. Data are mean and SD. (a) Pre-surgery > post-surgery (6 wk); post-surgery; (8 wk); post-surgery (10 wk) ($p< 0.05$).