FORCE TRACE CHARACTERISTICS IN ANTERIOR CRUCIATE LIGAMENT DEFICIENT AND UNINJURED KNEES DURING A MAXIMAL ISOMETRIC TASK

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Anterior cruciate ligament (ACL) deficiency has been shown to alter the muscle function of the leg. This study aimed to investigate differences in force trace characteristics of a maximal isometric task between ACL deficient and uninjured knees. Six ACL injured and uninjured participants completed maximal adduction, extension, and flexion isometric contractions. Peak, mean, standard deviation (SD), coefficient of variance (CV), frequency and signal regularity were calculated for all trials. Mean flexion force was larger in the ACL intact (0.91 N/kg) compared to their deficient (0.67 N/kg; $p<0.05$) knee. SD, CV and frequency composition of the extension trial differed between limbs in the uninjured ($p<0.05$). Analysis of variability, frequency and regularity of a signal may provide information on the function of the knee.

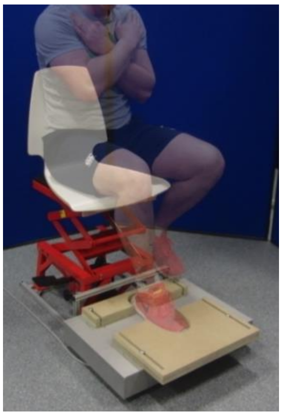
KEY WORDS: peak, variability, frequency, entropy.

INTRODUCTION: Anterior cruciate ligament (ACL) rupture has been associated with changes in the function of the knee (Trulsson, Miller, Hansson, Gummesson, & Garwicz, 2015). Peak knee torque has been shown to be lower in the ACL deficient knee compared to the uninjured limb (Kim, Lee, Ahn, Park, & Lee, 2016). The assessments of peak torques are often used in ACL monitoring, specifically when considering readiness to return to sport for an athlete (Knezevic, Mirkov, Kadija, Milovanovic, & Jaric, 2014).
The ACL, in addition to providing mechanical stability to the knee, contributes to proprioception. The loss of mechanoreceptors in the ACL has been shown to result in a proprioceptive deficit within the knee (Godinho et al., 2014), which may alter the characteristics of a maximal isometric task. During maximal contractions, large forces are placed on the knee which may cause movement of the tibia or femur. This movement in uninjured knees is controlled and resisted by the proprioceptive elements, including the ACL. Therefore the absence of the ACL may result in changes to the force outputs when an isometric contraction is performed.
Research has previously used signal characteristics to distinguish between participants with good and poor motor control function (Chow & Stokic, 2014). It was found that using frequency and entropy analysis on knee torque data, stroke suffers elicited lower frequency and reduced signal complexity. The frequency, variability and disorder of a force signal has yet to be applied to ACL deficient participants, but may give information on the changes in motor control and proprioception due to rupture. Hence, this research aims to investigate force signal characteristics of maximal isometric contractions in ACL deficient and uninjured knees.

METHODS: Six ACL injured (Mean±SD; age: 25.3±8.0 years; height: 1.77±0.10 m; mass: 87.0±32.3 kg) and uninjured (Mean±SD; age: 26.8±3.8 years; height: 1.76±0.04 m; mass: 80.3±7.1 kg) participants took part in this study. ACL injured participants were recruited through an orthopedic surgeon’s caseload and assessed for inclusion (unilateral ACL rupture & 18-45 years old) and exclusion (other lower limb surgery ≤3 months, or; current acute injury affecting other lower-extremity joints, or other relevant neurological or musculo-

skeletal pathology) criteria. Uninjured participants were recruited through the local population and assessed for similar criteria yet exclusion was unilateral ACL rupture.
The side of injury and self-reported leg dominance were recorded. A custom built adjustable seat, and force plate (Kistler 9281CA; 1000 Hz) were used for data collection (Figure 1a). The height of the seat was adjusted so the participant's knee was in 90° of flexion when seated. A wooden jig was adjusted to fit the participant's foot and fixed to the force plate. Participants were instructed to push their foot against the wooden jig as hard as possible for 10 s, starting on a verbal signal that was given 1 s into the recording of the trial. Adduction, extension and flexion trials were completed twice for each leg in a randomised order.
Data were processed using a custom MATLAB code (R2016b, The MathWorks, Inc.). The relevant horizontal force vector was extracted for each movement direction and normalised to body mass.

a)



b)

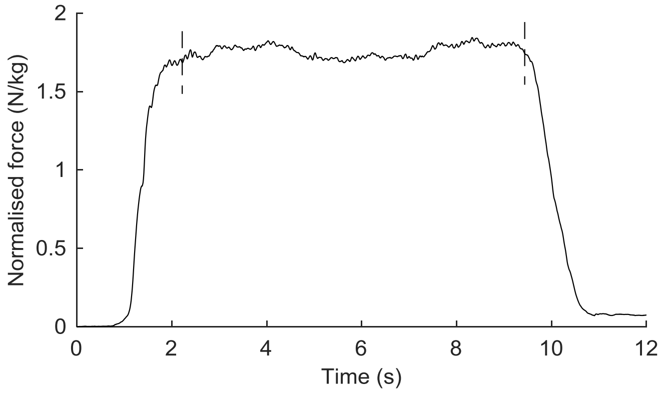


Figure 1: a) Adjustable seat, force plate, and foot rig; b) Example normalised horizontal force with identified boundaries of interest (dashed lines).

The section of each trial where the participant was producing and maintaining a maximal force was identified using a method for classifying the point of stabilisation (Figure 1b; Colby, Hintermeister, Torry, & Steadman, 1999). Defined as the time point where the cumulative mean crossed the total mean minus the standard deviation (SD). This method was applied to the first half of the data (0 – 6 s) and then to the reverse of the second half (6 – 12 s) to calculate the start and end points to analyse. Mean, SD, and coefficient of variation (CV) were calculated for all trials.
Using a fast Fourier transform the cumulative percentage of data under 10 Hz was calculated. To cater for varying trial lengths, standardised bin size were set to 2 Hz, and the percentage of data in each bin (0-2, 2–4, 4–6, 6–8, and 8–10 Hz) calculated. Sample entropy (Richman & Moorman, 2000) with vector length (m) set at 2 and tolerance (r) to 0.2×SD was used to establish the complexity of the data.
Means of the two trials in each condition were compared using Wilcoxon signed-rank tests for intra participant (dominant – non-dominant; ACL intact – ACL deficient) differences and Mann–Whitney U tests to investigate between group (dominant - ACL intact; non-dominant-ACL deficient) differences. Statistical significance level was set to 0.05.

RESULTS: Peak force was 15% and 17% lower in the ACL deficient knee compared to the ACL intact for extension and flexion tasks respectively (Table 1). No significant differences were found between peak force for any comparison. Significant differences were found between limbs for the SD and CV for uninjured participants during the extension trial, and mean force for ACL injured participants during the flexion trial. Sample entropy was significantly lower in the ACL deficient knee compared to the non-dominant knee of the uninjured participants (Table 1) during the adduction trials.

Table 1
Mean ± SD peak, mean, standard deviation (SD), coefficient of variation (CV), and sample entropy (SampEn) of all trails for both limbs of the uninjured and ACL injured participants

	Uninjured		ACL Injured	
	Dominant	Non-dominant	ACL intact	ACL deficient
Adduction				
Peak (N/kg)	1.42 ± 0.26	1.50 ± 0.27	1.17 ± 0.53	1.22 ± 0.58
Mean (N/kg)	1.08 ± 0.22	1.17 ± 0.28	0.91 ± 0.47	0.92 ± 0.51
SD (N/kg)	0.14 ± 0.05	0.14 ± 0.04	0.12 ± 0.05	0.12 ± 0.05
CV	13.07 ± 6.27	13.06 ± 4.96	14.87 ± 6.40	14.64 ± 5.51
SampEn	0.018 ± 0.006	0.016 ± 0.004$^{\phi}$	0.015 ± 0.005	0.013 ± 0.004$^{\phi}$
Extension				
Peak (N/kg)	3.39 ± 0.63	3.37 ± 0.97	2.36 ± 1.12	1.99 ± 1.19
Mean (N/kg)	2.79 ± 0.43	2.74 ± 0.87	1.88 ± 0.88	1.58 ± 0.97
SD (N/kg)	0.24 ± 0.14 †	0.33 ± 0.18 †	0.22 ± 0.16	0.18 ± 0.09
CV	8.62 ± 5.29 †	12.86 ± 6.86 †	12.11 ± 6.28	12.52 ± 4.33
SampEn	0.019 ± 0.003	0.015 ± 0.009	0.014 ± 0.005	0.019 ± 0.011
Flexion				
Peak (N/kg)	1.52 ± 0.79	1.54 ± 0.70	1.10 ± 0.36	0.91 ± 0.37
Mean (N/kg)	1.28 ± 0.72	1.28 ± 0.57	0.91 ± 0.28 †	0.67 ± 0.22 †
SD (N/kg)	0.11 ± 0.06	0.13 ± 0.11	0.09 ± 0.05	0.09 ± 0.07
CV	8.99 ± 1.69	9.58 ± 5.01	9.41 ± 3.24	14.02 ± 7.94
SampEn	0.024 ± 0.009	0.025 ± 0.008	0.025 ± 0.013	0.018 ± 0.010

† denotes significant difference between limbs; $^{\phi}$ denotes significant difference between groups

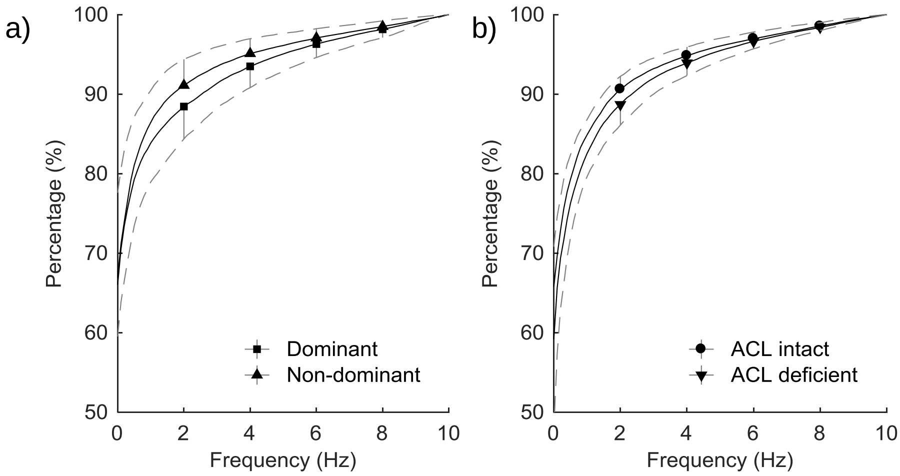


Figure 2: Mean and standard deviation (dashed line) of percentage data under 10 Hz for both limbs for a) uninjured and b) injured participants for the flexion trial.

A significantly higher percentage of data were between 8 – 10 Hz for the non-dominant leg compared to the dominant leg (Mean±SD; dominant: 1.397±0.639 vs non-dominant: 1.531±0.715) for the extension trial. Mean percentage of data represented by each frequency was not significantly lower in the ACL deficient knee and dominant leg compared to the ACL intact and non-dominant respectively during the flexion trial (Figure 2).

DISCUSSION: Through investigating the force signal characteristics of maximal isometric contractions in ACL deficient and uninjured knees, significant differences in variability and frequency composition that may show variances in the performance of the isometric tasks were found. The only difference identified between ACL intact and deficient knees was in mean force during a maximal flexion task.

The absence of differences in peak force between limbs in the ACL injured participants is in contrast to previous research (Kim et al., 2016). This may be explained by methodological differences. Isokinetic dynamometers, the most common method for collection of knee torques, although offer isolation of a joint are both expensive and unsuitable for widespread clinical use. The tools used in this research, if found to be sensitive, are suitable for simplification meaning their widespread implementation is plausible. The data presented here does not provide evidence that the employed testing protocol is sensitive to distinguish between ACL deficient and uninjured knees. Further research should look to identify if the testing procedure is sensitive to identify the increased deficit in strength after ACL reconstruction (Knezevic et al., 2014)

Variability (SD and CV) was found to be significantly larger in the non-dominant limb compared to the dominant limb in the uninjured participants during the extension trial. In addition, the non-dominant limb also had an increased percentage of data in the 8 – 10 Hz frequency bin. Both variability and frequency have been identified as markers of poor motor control (Chow & Stokic, 2014), and the identification of these differences in uninjured participants suggest that differences in muscle function exist between limbs regardless of injury. No significant differences were found for variability or frequency between limbs in ACL injured participants. The largest differences where observed in the frequency data of the flexion trial (Figure 2b). The lack of significant differences in the ACL injured group may suggest these participants are able to compensate for the loss of the ligament. The increased signal complexity in the adduciton trial for the ACL deficient knee does offer some evidence for altered knee function during a maximal isometric task after ACL rupture. Further work is needed to confirm the suitablity of the chosen analysis to distinguish between ACL deficient and unijured knees, however there is evidence that analysis investigating the characteristics of the force trace during maximal contractions may offer insight into knee function.

CONCLUSIONS: The use of only peak forces may be too simplistic when evaluating performance of maximal isometric tasks. Further understanding of performance of such tasks change through the treatment process may lead to more thorough readiness to return to sport assessments, reducing the risk of early return.

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