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HAMSTRING MUSCLE ENDURANCE IN SUBJECTS WITH PRIOR KNEE INJURIES

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Abstract:
Background: Knee joint is a common site for injury among younger people, the purpose of this study is to measure the skeletal muscle endurance and strength on people with prior knee reconstruction surgery. **Methods:** Young healthy female subjects were tested who reported having knee reconstruction surgery of over one year prior to testing. The skeletal muscle endurance index of the hamstring and quadriceps muscles was determined as the decline in the specific muscle acceleration in response to 2, 4, and 6 Hz electrical stimulation. Maximal isometric muscle strength (MVC) was measured in the hamstring and quadriceps muscles. **Results:** The hamstring muscles in the affected leg had less endurance than the non-affected leg at 6 Hz stimulation (55.5 $\pm$ 13.2% versus 78.0 $\pm$ 13.3%, P = 0.01). Muscle endurance was not reduced in the quadriceps muscles in the affected leg compared to the non-affected leg at 6 Hz stimulation (78.0 $\pm$ 13.3% versus 80.3 $\pm$ 10.0%, P = 0.69). There were no differences in MVC between the affected and non-affected legs for either the hamstring (P= 0.20) or quadriceps muscles (p = 0.67). **Conclusions:** Muscle endurance is reduced in the hamstring muscles at least one-year post injury, while hamstring strength is not. Reduced hamstring muscle endurance could be a result of a lack of focus on muscle endurance during rehabilitation after injury and may contribute to re-injury in the particular muscle even in people who have recovered muscle strength.

Keywords- Endurance, Fatigue, Skeletal Muscle, Knee rehabilitation

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1. Introduction

The knee joint is a common site for injury among younger people, and muscle weakness commonly persists in individuals who return to activity following anterior cruciate ligament reconstruction [1, 2]. People are more likely to suffer from an injury because they are spending their leisure time practicing sporting activities. A 10-year study documented 17,397 patients with 19,350 sport injured, and other knee injuries, the anterior cruciate ligament (ACL) was damaged in 45.4% of the cases of internal knee injuries [3]. Moreover, female athletes report anterior cruciate ligament injuries at a 4-to-6-fold greater rate than male athletes [4]. Most athletes, however, do not successfully return to their pre-injury sport despite reaching the acceptable requirements for muscle function [5].

Rigorous rehabilitation after anterior cruciate ligament reconstruction is necessary for a successful outcome [6]. However, rehabilitation is largely based on a recovery period centered around sports, so the primary focus of therapy is on accelerated muscle strength gains [6]. Therefore, the underlying body of research that physical therapy is based off emphasizes the importance of muscle strength [7-9]. Muscle endurance, in contrast, is not a focus of physical therapy following a knee injury, and impaired muscle endurance could lead to reduced muscle strength during activities. If the hamstring muscle has reduced endurance compared to the quadriceps muscle, muscle weakness and imbalance between muscles could develop while performing sustained exercise. This unsuccessful recovery following a knee injury may be associated with inadequate rehabilitation and muscle imbalance, particularly of the hamstring muscle.

The purpose of this study was to measure the muscle endurance in the hamstring and quadriceps muscles following reconstructive surgery for a knee injury. A non-invasive measure of muscle specific endurance has been developed to allow testing of muscle fatigue in the hamstring and quadriceps muscle independent from motor activation [10-12]. It was hypothesized that subjects who have undergone reconstructive surgery and physical therapy will have impaired hamstring muscle endurance in their affected leg compared to their non-affected leg.

2. Materials and Methods

Study Population. Eight female subjects were tested. The subjects reported a knee injury and completed physical therapy at least 12 months prior to testing. All subjects had resumed a recreationally active lifestyle. This study was approved by University of Georgia, Athens Institutional Review Board, and each subject signed an informed consent form before participating in the study.

Experimental Protocol. This study is a one group design where both hamstring and both quadriceps muscles were tested in each subject. Each subject was tested in a single day. The subjects were asked to report their recent activity level or what sports or activities they perform on a weekly basis. During testing, each subject participated in an endurance test of the four muscles. Following the endurance test, the subjects were tested for muscle strength of their hamstring and quadriceps of the affected and non-affected leg with an isokinetic ergometer (Biodex).

Endurance test. A muscle specific endurance test was performed as reported previously [10]. The subjects were positioned prone on a padded table, and the accelerometer was attached the subject’s skin with double-sided tape and placed on the belly of the muscle. Two electrodes 4 x 5 cm were placed 2-3 cm proximal and distal to the accelerometer. The muscles were stimulated using current levels between 30 and 50 mA. The level of current was based on the visibility of muscle twitch and the pain tolerance or comfortability of the subject. Previous studies have shown

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the endurance index measurements to be independent of current level [10]. The triaxial accelerometer was set to collect data at 400 Hz (WAX-3, Axivity UK). Stimulation consisted of 2, 4, and 6 Hertz stimulations for three minutes each with ten seconds of rest in-between and a 30 second baseline established before and after each interval of study. Declines in the acceleration of the muscle twitch contractions was used to calculate muscle endurance.

Muscle strength. A Biodex System 4 Quick Set was used to measure the strength of the subject's hamstrings and quadriceps [13]. The subject sat in the chair, and one leg was strapped into a lever that measured the torque (Newton-Meters) with which the subject was kicking out, measuring the strength of the quadriceps, or pulling back, measuring the strength of the hamstring. A total of six measurements are collected, three for the quadriceps and three for the hamstring, and the average of all three values is taken to calculate a single strength value for each muscle. This was completed on both legs of each individual.

Data analysis. Data from the accelerometer was transferred to Microsoft Excel, and a resultant vector was calculated. Further analysis was done in MATLAB R2017b (Mathworks inc., USA) using a customized written analysis program, where percentage decline in acceleration for the 2, 4, and 6 Hz frequencies was calculated. Endurance Index data was calculated as the percent of acceleration at the end of each stimulation frequency in relation to its peak value (12).

Statistical analysis. A two-way between and within subject Analysis of Variance (ANOVA) was used to evaluate the difference between the injured and non-injured leg and the effect of the three frequencies of stimulation (2, 4, and 6), this was done for both Hamstrings and Quadriceps muscles. A two-way ANOVA was also used to evaluate the difference between the Hamstring muscle and the Quadriceps muscle, and the effect of the stimulation frequency. A follow up pairwise comparison was done for each pair of the stimulation frequency. A 2x2 ANOVA was conducted to evaluate the difference between strength of the Non-injured and the injured leg, and the Hamstring and the Quadriceps.

3. Results

Data was completed on eight females with prior knee injury (average duration 54 months, range was 29-94 months). Table 1 shows the descriptive statistics of the participants. Figure 1a (Hamstring) and 1b (Quadriceps) shows the representative figure of the endurance graph of one of the participants.

3.1. Hamstring Endurance:

Fig 2a shows the mean and standard deviation of the Endurance Index of the participants in each group (Non-injured and Injured, Hamstrings and Quadriceps) respectively. The hamstring muscle in the affected leg had lower endurance than the non-affected leg at 2 Hz (86.3 $\pm$ 6.3 versus 90.5 +4.9), 4 Hz (70.5 $\pm$ 12.2 versus 80.1 + 6.9, and 6 Hz stimulation (55.5 $\pm$ 13.2% versus 73.9 $\pm$ 12.3%), $F(1,14)=11.45, p<0.001$). There was also a significance difference in the effect of the frequency ($F(2,28)=26.26, p<0.001$).

3.2. Quadriceps Endurance:

Figure 2b shows the mean and standard deviation of the Endurance Index of the quadriceps. Mixed factor ANOVA shows there was no significant difference in the Endurance Index of the Quadriceps muscle between the Injured and the non-Injured leg $F(1,14)=0.609$, $p=0.0448$), although the within factor showed a significant effect of frequency ($F(2,28)=14.80$, $p<0.01$). 2x2 between-subject ANOVA showed that there was a significant difference in Endurance Index between the Hamstring and the Quadriceps of the non-injured leg ($F(1,14)=7.794$, $p<0.01$) within

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subject ANOVA also shows a significant effect of the stimulating Frequency (F2,28)=15.33, p<0.01).

3.3. Muscle Strength:

The mean and standard deviation of the muscle strength of both Hamstring and Quadriceps muscle is shown in Figure 2. A 2x2 ANOVA shows there was no significant difference in muscle strength of the Injured and non-injured leg (F(1,28)=0.027, p=0.87), but there was a significant difference between the muscle strength of the Hamstring and the muscle strength of the Quadriceps muscle F=1,28)=24.84, p<0.01) of both Injured and Non-injured-leg.

3.4 **Tables and Figures**

Table 1 Relevant Participant Demographics.

Subject	**Gender**	**Age (yr)**	**Weight (kg)**	**Height (cm)**	**BMI ($kg•m^{-2}$)**	**Duration (months)**	**Surgery Type**	**Physical Activity**
1	F	19	61.2	162.6	23.2	29	Quad Graft	Occasional rock climbing
2	F	21	65.8	167.6	23.4	59	Hamstring Graft	Running 4x/wk + weights
3	F	21	65.8	160.0	25.7	39	Cadaver	Running 4x/wk + weights
4	F	21	63.5	167.6	22.6	36	Patella Tendon	Elliptical 4x/wk + weights
5	F	21	55.3	170.2	19.1	48	Hamstring Graft	Running 4x/wk + weights
6	F	22	56.7	154.9	23.6	94	Hamstring Graft	Running 5x/wk + weights
7	F	21	69.9	170.2	24.1	84	Hamstring Graft	Cycle 2x/wk, soccer 1x/wk. + weights
8	F	31	64.4	167.6	22.9	43	Cadaver	2mi 2x/wk + weights
Mean ± SD		22.1 ± 3.7	62.8 ± 4.9	165.± 5.4	22.1 ± 3.7	54 ± 23.5		

Notes. Duration- months between date of surgery and date tested in research lab.

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Figure 1

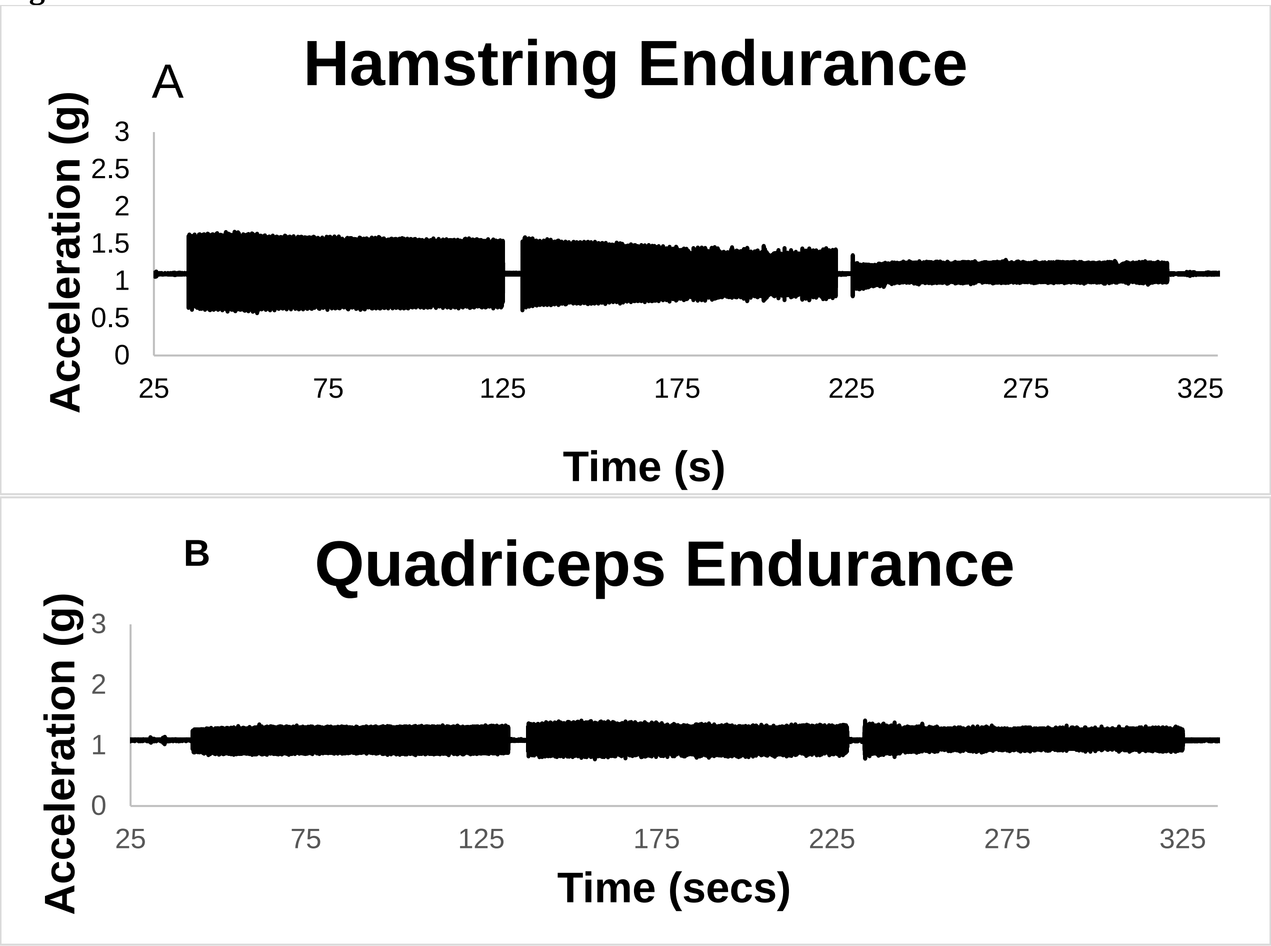

FIGURE 1. A) A representative example of hamstring endurance in the injured leg of tested individuals with 2, 4, and 6 Hz stimulation. **B)** A representative example of quadriceps endurance in the injured leg of tested individuals with 2, 4, and 6 Hz stimulation.

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Figure 2

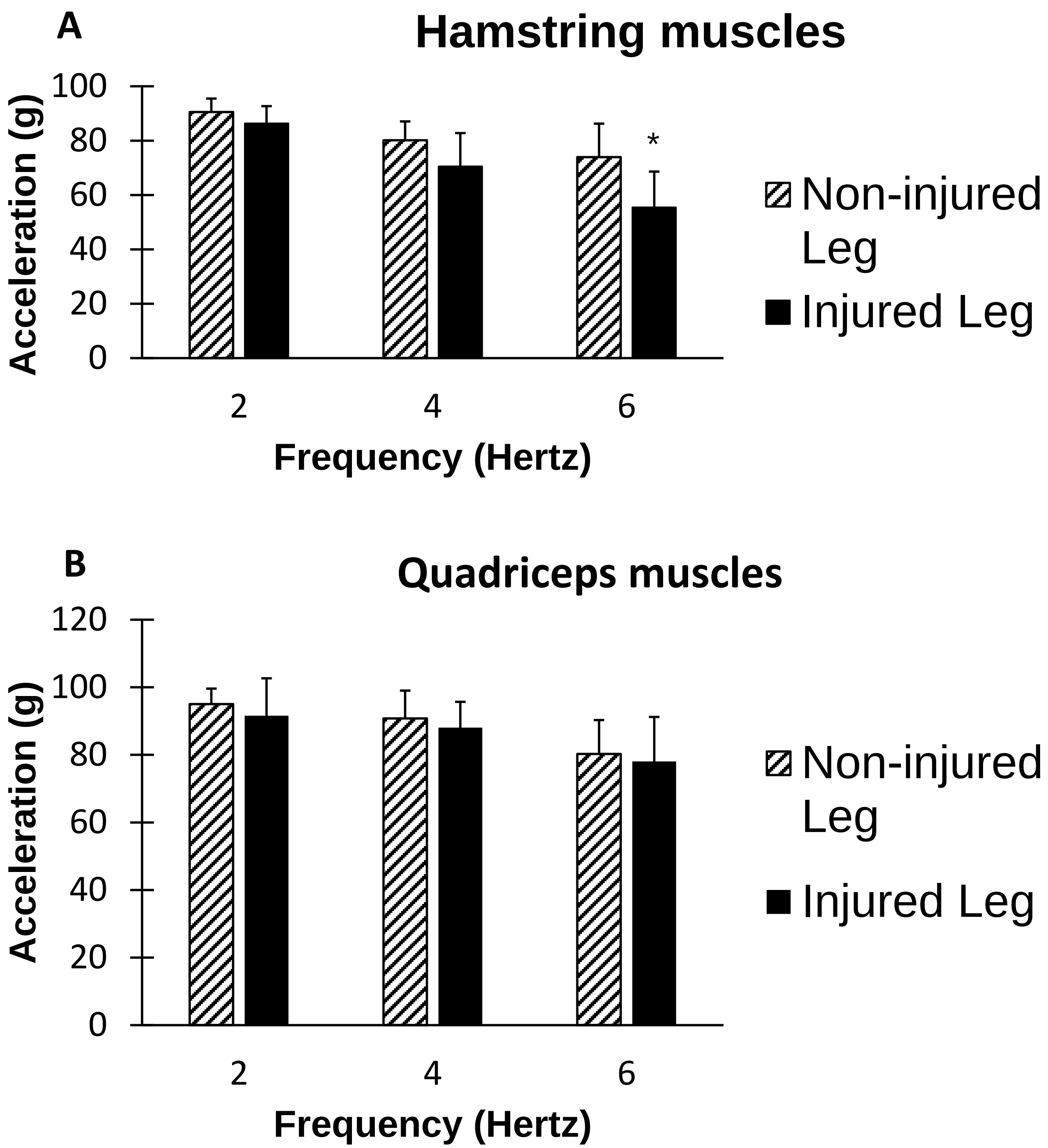

FIGURE 2. A) Mean and standard deviation of the Endurance Index for the Hamstring Muscle for the 3 electrical stimulation frequency (2hz, 4hz, 6hz) for each leg. **B**) Mean and standard deviation of the Endurance Index of the Quadriceps muscle at the 3 electrical stimulation frequency (2hz, 4hz and 6hz) for each leg. * represent significant difference.

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Figure 3

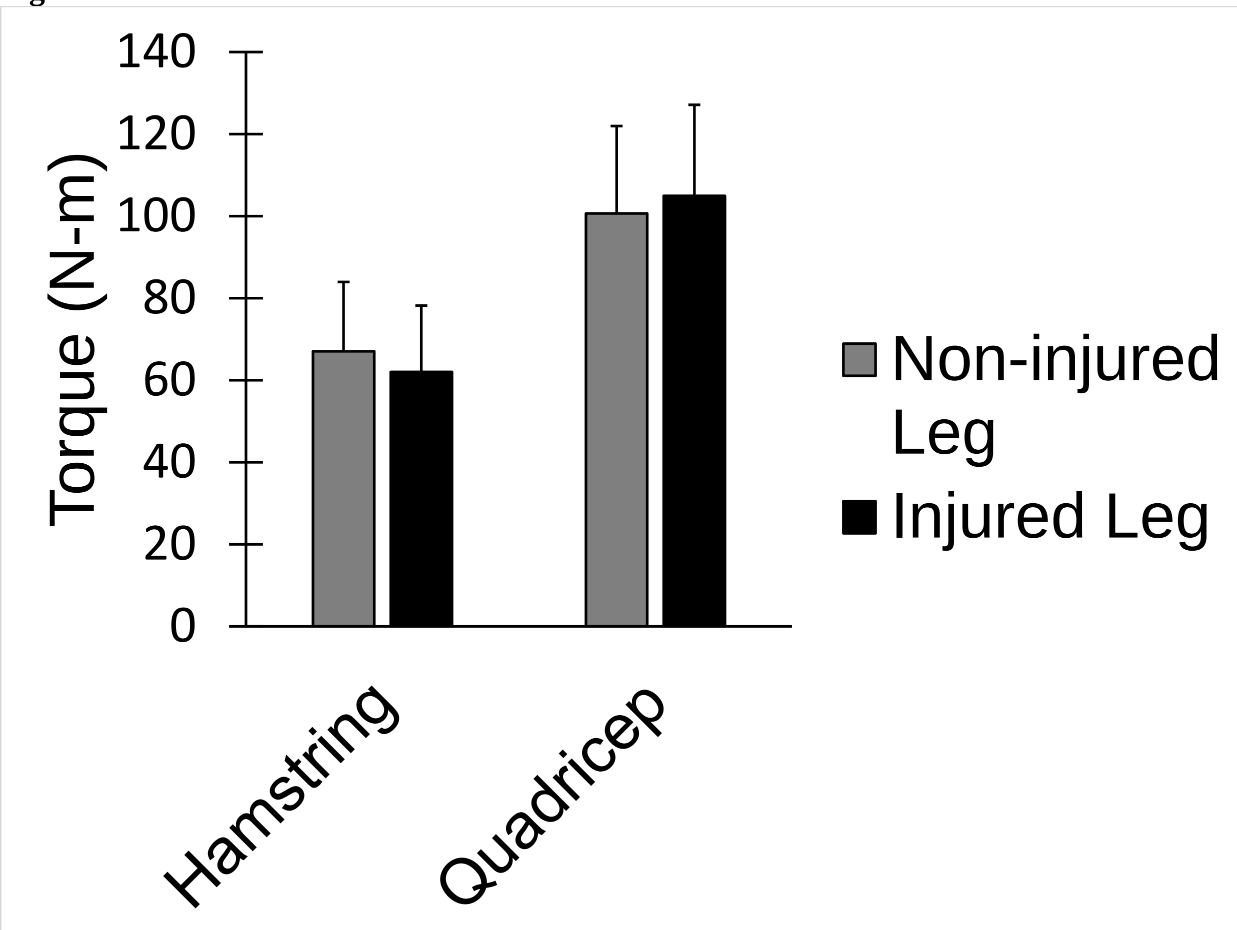

FIGURE 3) The muscle strength of the hamstring and quadriceps. There was no significant difference between the injured and non-injured legs. Values are means (SD).

4. Discussion

The main finding of this study is that the hamstring endurance in the affected leg was reduced in individuals with prior knee injuries. We were not able to find many studies that evaluated muscle endurance after knee surgery. One study found quadriceps muscle endurance to be reduced compared to controls 18 months after surgery, with no change in hamstring muscle endurance at the same time [14]. However, the endurance protocol used was not described other than it was performed with an isokinetic ergometer at various muscle speeds. That study did not make comparisons to the non-affected leg. Another study found no differences in hamstring or quadriceps muscle endurances 26 months following injury [15]. The endurance test consisted of the total knee flexion work performed in 45 seconds using an isokinetic ergometer. The endurance protocol in this study, however, was different because it did not rely on voluntary muscle contractions. Previous studies have reported long term deficits in perceived and functional outcomes that maybe related to central factors. Central factors do not play a role in the endurance test used in this study because of the use of electrical stimulation to produce muscle contractions

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[10]. Our results are consistent with a previous study that reported reduced trunk muscle endurance at least one year following ACL reconstruction surgery [16]. Werner et al. concluded that inadequate rehabilitation of the trunk muscles was the reason for the deficit in trunk muscle endurance [16].

In our study, we found that hamstring and quadriceps muscle isometric strength were similar in the affected and non-affected legs. Previous studies have reported strength deficits in the affected leg for both the hamstring and quadriceps muscles [17]. However, some of these deficits are not apparent 2-3 years post injury [18], consistent with our results. We found the ratio of quadriceps to hamstring muscle strength to be within the range expected of healthy uninjured people, suggesting our participants did recover their strength even if the hamstring muscle endurance did not recover.

Our study has a number of limitations. We made our measurements an average of 4.5 years after the injury. This is longer than most studies that look at muscle function post injury. Our study does not allow us to make any conclusions on the potential time course of changes in muscle endurance, relative to changes in muscle strength. In this study, we did not correct by type of surgery to repair the injured knee. Literature addresses that among all of the different grafts used in ACL reconstruction, bone-patella tendon-bone, hamstrings, allograft and synthetic grafts, that there is not a “best” graft, but that there are clear differences between the different surgical options [19]. These different methods of repair may have an effect on the recovery of muscle endurance and strength, and this could be a topic of interest for further research. This study only focused on female subjects, in part due to the available research subject pool [15]. As previously stated, females are more likely than males to suffer from a knee injury, most specifically a torn anterior cruciate ligament [20-23]. The sex of the subject may also play a role in their recovery following reconstructive surgery, but more research needs to be done in this area [24]. We also did not look specifically at rehabilitation because we tested recreational athletes where rehabilitation was up to the individual, but on average, the subjects still expressed a deficit in muscle endurance years post-surgery. This study was not prospective, so we cannot conclude that weakness leads to injury. However, athletes with hamstrings to quadriceps ratios below the normal ranges are more likely to sustain an overuse injury, so balancing muscle endurance may work to reduce this likelihood of injury or re-injury [25].

This research is relevant because following the ankle, the knee joint is the second most commonly injured body part, and knee injuries are the leading cause of sport-related surgeries [26]. The effectiveness of rehabilitation and full recovery following a sustain knee injury are largely based on literature [27]. Therefore, these finding have the potential to transform rehabilitation following anterior cruciate ligament reconstructive surgery by including an emphasis on rehabilitation of muscle endurance along with rehabilitation for strength.

5. Conclusion

Muscle endurance is reduced in the hamstring muscles at least one-year post injury, while hamstring strength is not. The hamstring muscle of the affected leg of the individual does not appear to fully recover following rehabilitation of an ACL knee injury. The quadriceps endurance, the hamstring and quadriceps strength does appear to recover. Reduced hamstring muscle endurance could be a result of lack of focus on muscle endurance during rehabilitation after injury and may contribute to re-injury in the particular muscle even in people who have recovered muscle strength. Additional studies, and perhaps a focus on muscle endurance during rehabilitation are needed to improve physical therapy and rehabilitation following knee injuries.

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Author Contribution

Jamie Faxon - Data collection, manuscript original draft, data analysis
Adeola Sanni – Statistical analysis, formal analysis, manuscript review and editing
Kevin McCully – Principal investigator, supervisor and revise manuscript

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Conflicts of interest: The authors have no conflict of interest to declare

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