Physical Therapy in Sport 40 (2019) 1–9

Contents lists available at ScienceDirect

Physical Therapy in Sport

journal homepage: www.elsevier.com/ptsp

Original Research

The relationships between kinesiophobia and clinical outcomes after ACL reconstruction differ by self-reported physical activity engagement

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A R T I C L E I N F O

Article history:
Received 13 May 2019
Received in revised form
6 August 2019
Accepted 7 August 2019

Keywords:
Fear
Hamstrings
Hop performance
Patient-reported outcomes

A B S T R A C T

Objectives: To investigate whether relationships between kinesiophobia, lower extremity function, and patient-reported function differ by self-reported physical activity engagement after ACL reconstruction (ACLR).
Design: Cross-sectional.
Setting: Laboratory.
Participants: Seventy-seven patients with a primary, unilateral ACLR.
Main outcome measures: Kinesiophobia (TSK-17) was the primary outcome. Lower extremity function included quadriceps and hamstrings strength, fatigue, and hop performance. Patient-reported function included regional function (IKDC, KOOS subscales) and physical activity engagement (Godin Leisure-Time Exercise). Patients were evaluated together, then stratified by LOW and HIGH physical activity. Correlations and multiple regression analyses identified relationships between kinesiophobia and outcome measures.
Results: Greater kinesiophobia was associated with lesser hamstrings strength, hop performance, and patient-reported function. Greater hamstrings fatigue and lesser $KOOS_{ADL}$ explained greater kinesiophobia in patients reporting LOW physical activity. Lesser triple hop symmetry, crossover hop distance, and IKDC explained greater kinesiophobia in patients reporting HIGH physical activity.
Conclusions: Greater kinesiophobia associated with worse outcomes after ACLR. Relationships differed by self-reported physical activity engagement. Interventions that improve the ability to perform knee-related activities of daily living may be appropriate to minimize the impact of fear in less active patients, while those targeting hop performance and knee-related sport activities may be better suited for more active patients.

1. Introduction

Despite a growing emphasis on the psychological impact of ACL reconstruction (ACLR), instruments designed to assess constructs such as kinesiophobia are historically underrepresented. Kinesiophobia has been defined as the unreasonable or irrational fear of pain and painful reinjury upon physical movement (Kori et al.,

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https://doi.org/10.1016/j.ptsp.2019.08.002
1466-853X/

1990). Previous authors (Everhart, Best, & Flanigan, 2015; Flanigan, Everhart, & Glassman, 2015) have highlighted the clinical impact of kinesiophobia, suggesting that fear of movement and reinjury can promote poor quality rehabilitation and decreased physical activity, yet this domain of patient-reported function has not been routinely included with traditional objective measures of lower extremity function in return-to-activity decision-making.

Elevated kinesiophobia has been reported beyond physician clearance (Lentz et al., 2015), despite early improvements during rehabilitation (Chmielewski et al., 2008, 2011). Psychological readiness is strongly associated with returning to preinjury activity (Ardern et al., 2013a, 2013b, 2014), yet nearly 3-in-4 patients have reported feeling unready to return once discharged from rehabilitation (Dempsey et al., 2017). Although a variety of psychological factors likely influence perceived readiness, several authors (Flanigan, Everhart, Pedroza, Smith, & Kaeding, 2013; Czuppon, Racette, Klein, & Harris-Hayes, 2014; Tjong, Murnaghan, Nyhof-Young, & Ogilvie-Harris, 2014; Kvist, Ek, Sporrstedt, & Good, 2005; Lentz et al., 2012; McCullough et al., 2012) have reported an association between lower fear and a higher rate of returning to preinjury activity after ACLR. Patients with elevated kinesiophobia have also demonstrated insufficient and asymmetric quadriceps strength (Lentz et al., 2015; Paterno, Flynn, Thomas, & Schmitt, 2018), asymmetric hop performance (Paterno et al., 2018), landing mechanics consistent with those at risk for ACL injury (Trigsted et al., 2018), increased likelihood for second ACL injury (Paterno et al., 2018), and poor subjective knee function (Lentz et al., 2015). Collectively, these data support the link between fear, physical performance, and regional health metrics utilized in return-to-activity decision-making.

According to the cognitive-behavior model of fear of movement and reinjury (Vlaeyen, Kole-Snijders, Boeren, & van Eek, 1995), patients' perception of fear may influence, or be influenced, by how physically active s/he is after surgery. Under this theory, less physically active patients could be more fearful of the anticipation of movement, or less fearful of movement, if it is no longer a part of their daily routine. To complicate the relationship between physical activity and fear, it is unclear which precedes the other. Interestingly, high-level athletes returning to cutting and pivoting sports who reported greater fear were more likely to report lower physical activity on the Marx Activity Rating Scale (Paterno et al., 2018). However, findings among elite athletes may not accurately represent a general population of patients intending to return to various activities of daily living.

Leisure-time physical activity is considered an important domain of public health intervention, and has been associated with risk for cardiovascular disease (Li, Loerbroks, & Angerer, 2013) and depressive symptoms (Teychenne, Ball, & Salmon, 2008). The Godin Leisure-Time Exercise Questionnaire is commonly used to assess leisure-time physical activity. It was originally described as a relative ranking method to assess community-based exercise behavior by summing weighted (based on metabolic equivalent of task) scores of strenuous, moderate, and mild exercise during a 7-day period (Godin & Shephard, 1985). This method has been used to demonstrate a reduction on leisure-time physical activity after ACLR compared with healthy controls (Norte, Hertel, Saliba, Diduch, & Hart, 2018a, 2018b). A classification system that omits mild exercise has since been described to categorize healthy individuals as active or insufficiently active using a cutoff score of 24 (Amireault & Godin, 2015). However, this classification system was validated among individuals 24–64 (mean = 45.5) years old, and may not accurately reflect physical activity engagement in young, active individuals based on a recent investigation (Norte et al., 2018a, 2018b) of patients nearly 4 years after ACLR, which reported a mean Godin score of 59.1 compared to 75.5 in healthy matched controls. Regardless, it is feasible that physical activity could influence the clinical impact of kinesiophobia after ACLR, yet this is currently unclear.

Therefore, our purpose was to investigate whether self-reported physical activity engagement influences existing relationships between kinesiophobia and clinical outcomes related to lower extremity function (strength, fatigue, hop performance) and patient-reported function (regional health, global health). We hypothesized that the relationships between kinesiophobia and clinical outcomes would differ based on level of self-reported physical activity engagement. Specifically, we hypothesized greater kinesiophobia would be associated with lesser hop performance due to the dynamic nature of those tests, and with patient-reported function in the total cohort. However, we hypothesized these relationships would differ between patients reporting high and low physical activity engagement, such that objective function would better explain kinesiophobia in more active patients and subjective function would better explain kinesiophobia in less active patients.

2. Methods

We used a cross-sectional study to investigate relationships between kinesiophobia, objective lower extremity function, and subjective patient-reported function in patients after ACLR. The primary outcome was kinesiophobia. Objective explanatory variables included measures of quadriceps and hamstrings strength, fatigue, and single-leg hop performance. Subjective explanatory variables included measures of physical activity engagement, regional health, and global health.

2.1. Participants

Seventy-seven patients between the ages of 13 and 47 were recruited from our University medical center and local community. All patients had undergone a primary, unilateral ACLR with either bone-patellar tendon-bone or semitendinosus-gracilis autograft, had completed their prescribed rehabilitation program, and enrolled at 6 months post-surgery prior to physician clearance for unrestricted physical activity. All patients were scheduled to be evaluated by their physician for clearance within several weeks following testing, which may have included the same day of testing. Regardless of whether patients were cleared at that time, all were included in this analysis. Patients with a history of failed ACLR, contralateral lower extremity surgery or injury within 6 months, treated chondral lesion, treated multiple ligament injury, or known osteoarthritis were excluded. Our Institutional Review Board approved this study, and all participants provided written and verbal consent.

2.2. Procedures

All participants completed study procedures according to protocol during a single session in the order described below, with the contralateral limb always tested first (Bodkin, Goetschius, Hertel, & Hart, 2017; DiFabio et al., 2018; Lisee, Slater, Hertel, & Hart, 2018; Menzer et al., 2017). The following tests were included based on the frequency of reported use in return to activity test batteries after ACLR. While passing test batteries that include measures of strength, hop performance, and patient-reported function are reported to influence the incidence of second ACL injury and graft rupture (Capin, Snyder-Mackler, Risberg, & Grindem, 2019), their association with kinesiophobia (Paterno et al., 2018) remains largely unclear.

2.2.1. Isokinetic strength

Extensor and flexor peak torque (Nm/kg), total work (J/kg), and average power (W/kg) were assessed at 90°/second using a stationary dynamometer (Biodex Medical Systems, Inc., Shirley, NY) as previously described (Norte et al., 2018a, 2018b). Participants completed at least two practice repetitions to become familiar with the task, followed by eight maximum effort test repetitions in a concentric/concentric manner with verbal encouragement and visual feedback of their force output. Participants always began with knee extension, followed by flexion. Data were averaged over the eight test repetitions for analysis.

2.2.2. Isometric strength and fatigue

Extensor and flexor maximum voluntary isometric contraction (MVIC) torque (Nm/kg) and fatigue (% decline) were assessed with the knee flexed to 90°. Participants performed several sub-maximal repetitions to become familiar with the task, followed by at least two practice trials at maximum effort. The fatigue index was then measured using a 30-s MVIC task as previously described (DiFabio et al., 2018; Norte et al., 2018a, 2018b; Surakka et al., 2004). In brief, participants were asked to either kick out (quadriceps) or pull back (hamstrings) as hard as possible, and to maintain that level of contraction for 30 s. The area under the force-time curve for the entire contraction period was used to quantify the fatigue index. Knee extension was always assessed first.

2.2.3. Single-leg hop tests

Four single-leg hops (single, triple, crossover, 6-m timed) were used to assess hop performance (Bodkin et al., 2017; DiFabio et al., 2018; Lisee et al., 2018; Menzer et al., 2017). Testing alternated between limbs, until three successful trials were recorded. Trials were considered successful if the participant reported maximal effort, did not touch the ground with the contralateral foot, and maintained balance upon landing.

2.2.4. Patient-reported outcomes

The Tampa Scale of Kinesiophobia-17 (TSK-17) was used to measure kinesiophobia, which has demonstrated adequate psychometric properties for chronic musculoskeletal pain (French, France, Vigneau, French, & Evans, 2007). The TSK-17 ranges from 17 to 68, with higher values representing more kinesiophobia (Vlaeyen et al., 1995). It is commonly used to assess fear avoidance, which suggests patients develop a negative psychological response to pain, or the anticipation of pain, that leads to an avoidance of movement due to fear of recurrent pain or injury (Vlaeyen et al., 1995). We have operationally defined kinesiophobia as fear of movement/(re)injury, and will refer to "fear" when interpreting the TSK-17. The Godin Leisure-Time Exercise Questionnaire (Godin & Shephard, 1985) was used to measure physical activity engagement, and has been validated as an effective relative ranking system in healthy adults (Godin & Shephard, 1985; Miller, Freedson, & Kline, 1994). Participants were instructed to consider a "typical 7-day period" of activity based on their current health state, and not prior to their injury. Godin scores could range from 0 to infinity, and were calculated using the described (Godin & Shephard, 1985) weighted sum of mild, moderate, and strenuous exercise, with higher values indicating more physical activity engagement. Regional health was measured using the International Knee Documentation Committee (IKDC) Subjective Knee Evaluation (range: 9–100%) (Irrgang et al., 2001) and the Knee Injury and Osteoarthritis Outcome Score (KOOS) (Roos & Lohmander, 2003) subscales (range 0–100%), with higher values indicating better knee function. Global health was measured using the Veteran's Rand 12-Item Health Survey (VR-12) total score, which is a summed composite of mental and physical components (Selim et al., 2009). The VR-12 could range from 0 to 100%, with higher values indicating better global health.

2.3. Data reduction

Isometric force data were acquired using a 16-bit digital acquisition system (MP150, BIOPAC Systems, Inc., Goleta, CA) with AcqKnowledge 3.7.3 software, sampled at 125 Hz, and low-pass filtered at 10 Hz. Peak MVIC torque was extracted from the fatigue task (DiFabio et al., 2018). Maximum hop distances or times were averaged from the three best trials, and normalized to body height. Data were reported for each limb, and expressed as a limb symmetry index (LSI).

2.4. Statistical analysis

Data were evaluated for normality. Pearson's r or Spearman's ρ correlations were used to identify associations between TSK-17 and each outcome measure in the total sample. Correlation coefficients were interpreted as negligible (0.0–0.3), low (0.31–0.5), moderate (0.51–0.7), high (0.71–0.9), or very high (0.91–1.0) (Mukaka, 2012). Separate stepwise multiple linear regression analyses were used to explain variance in TSK-17 using correlated measures of lower extremity and patient-reported function from the total cohort. Explanatory variables that were very highly correlated (>0.9) with one another were reduced to only include the highest correlated variable to avoid multicollinearity. To ensure ≥10:1 subject-variable ratio, we limited to a maximum of 7 explanatory variables per model. Probability thresholds were set to 0.05 (entry) and 0.10 (removal) with pairwise deletion. Patients were then stratified by Godin scores after all data reduction to minimize investigator bias. Godin scores below the median were operationally defined as LOW physical activity, and those at or above the median were defined as HIGH physical activity. Correlations and regression analyses were repeated within strata as described above. Lastly, independent t-tests, Mann-Whitney U tests, and Chi-squared tests were used as appropriate to compare outcomes between strata. All statistical analyses were performed at an alpha level of $P \le .05$.

3. Results

Patient demographics and patient-reported outcome measures are presented in Table 1 for the total cohort and by self-reported physical activity level. Significant correlations between TSK-17 and explanatory variables are summarized below and presented in Table 2. Squared correlation coefficients for all outcome measures are presented in Fig. 1. Multiple regression results are presented in Table 3.

3.1. All patients

TSK-17 demonstrated low correlations with Godin, IKDC, triple hop distance, and crossover hop distance. TSK-17 demonstrated negligible correlations with $KOOS_{symptoms}$, $KOOS_{ADL}$, $KOOS_{QOL}$, VR-12, isokinetic flexion torque, isokinetic flexion work, isokinetic flexion power, flexion MVIC torque, single hop distance, single hop symmetry, and triple hop symmetry. When entered into a multiple regression model, lesser crossover hop distance ($R^2 = 0.109$, $B = -3.237$, $P = .004$) and $KOOS_{ADL}$ ($R^2 = 0.189$, B = -.307, $P < .001$) explained greater kinesiophobia in the total cohort.

3.2. Low physical activity

TSK-17 demonstrated low correlations with IKDC, $KOOS_{symptoms}$, and $KOOS_{ADL}$, $KOOS_{QOL}$, VR-12, extension fatigue, and flexion fatigue. When entered into a multiple regression model, greater

Table 1
Demographic and patient-reported outcomes between patients reporting high and low physical activity after ACL reconstruction (mean ± SD).

	Total Cohort (n = 77)	High Physical Activity (n = 39)[a]	Low Physical Activity (n = 38)[a]	*P* values High vs. Low Physical Activity
Gender[b]	35 female, 42 male	18 female, 21 male	17 female, 21 male	.901
Age (years)	21.6 ± 7.8	21.4 ± 7.1	21.7 ± 8.5	.881
Height (cm)	173.4 ± 9.5	173.7 ± 10.4	173.2 ± 8.5	.824
Mass (kg)	75.4 ± 17.3	74.9 ± 16.0	76.0 ± 18.8	.785
Tampa scale of kinesiophobia	32.9 ± 6.0	31.4 ± 5.3	34.4 ± 6.3	**.030**
Godin leisure-time exercise	72.7 ± 34.9	98.2 ± 27.3	46.6 ± 18.8	< **.001**
IKDC (0–100)	81.6 ± 11.5	83.1 ± 10.2	80.1 ± 12.6	.252
KOOS pain (0–100)	91.4 ± 9.2	92.7 ± 7.6	90.0 ± 10.5	.196
KOOS symptoms[c] (0–100)	83.8 ± 13.1	85.5 ± 12.0	82.0 ± 14.2	.272
KOOS activities of daily living[c] (0–100)	96.5 ± 8.3	97.4 ± 3.6	95.5 ± 11.2	.983
KOOS sport and recreation (0–100)	81.5 ± 16.8	85.1 ± 12.1	77.8 ± 20.1	.057
KOOS quality of life (0–100)	66.7 ± 20.7	69.4 ± 19.9	63.8 ± 21.5	.241
Veteran's rand 12-item health survey (0–100)	80.3 ± 9.8	83.1 ± 8.0	77.4 ± 10.7	**.011**
Graft type, *n* (%)[b]	51 (66.2) BPTB 26 (33.8) STG	26 (66.7) BPTB 13 (33.3) STG	25 (65.8) BPTB 13 (34.2) STG	.935
Time since surgery (months)	6.3 ± 1.0 (range: 4.2–8.7)	6.1 ± 1.0 (range: 4.5–8.7)	6.4 ± 1.1 (range: 4.2–8.7)	.190

Abbreviations: IKDC, international knee documentation committee subjective knee evaluation form; KOOS, knee injury outcome and osteoarthritis score; BPTB: bone-patellar tendon-bone; STG: semitendinosus-gracilis.
Statistically significant at $P \leq .05$.
[a] Threshold for HIGH and LOW physically activity based on median Godin Leisure-Time Exercise = 73.0.
[b] Compared using Chi-squared tests.
[c] Compared using Mann-Whitney U tests.

Table 2
Significant correlation coefficients between kinesiophobia and clinical outcome measures in patients reporting low and high physical activity levels after ACL reconstruction.

	Total Cohort (n = 77)	High Physical Activity (n = 39)	Low Physical Activity (n = 38)
	Kinesiophobia (TSK-17)[a]		
Patient-Reported Outcomes			
Godin leisure-time exercise	-.312	NA	NA
IKDC	-.402	-.367	-.441
KOOS symptoms[b]	-.294		-.434
KOOS activities of daily living[b]	-.303		-.443
KOOS quality of life	-.305		-.375
Veteran's rand 12-item health survey[b]	-.297		-.386
Strength			
IK Peak Torque: EXT		-.334	
IK Average Power: EXT		-.401	
IM Torque: EXT		-.370	
IK Peak Torque: FLEX	-.243	-.432	
IK Total Work: FLEX	-.271	-.460	
IK Average Power: FLEX	-.282	-.473	
IM Torque: FLEX	-.288	-.350	
LSI IK Peak Torque: FLEX		-.383	
Fatigue			
Fatigue Index: EXT			.336
Fatigue Index: FLEX			.346
Hop Performance			
Single Hop	-.286	-.473	
Triple Hop	-.323	-.504	
Crossover Hop	-.331	-.541	
LSI Single Hop[b]	-.301	-.506	
LSI Triple Hop[b]	-.243	-.530	
LSI Crossover Hop[b]		-.416	

Abbreviations: TSK, Tampa Scale of Kinesiophobia; IKDC, international knee documentation committee subjective knee evaluation form; KOOS, knee injury outcome and osteoarthritis score; IK, isokinetic; IM, isometric; EXT, extension; FLEX, flexion; LSI, limb symmetry index.
[a] All correlations presented were statistically significant at $P \leq .05$. Heat maps are presented to the right of each group to depict the strength of correlation, where a darker color indicates a stronger correlation.
[b] Spearman's ρ correlations.

hamstrings fatigue ($R^2 = 0.118$, $B = 0.201$, $P = .038$) and lesser $KOOS_{ADL}$ ($R^2 = 0.299$, $B = -.307$, $P < .001$) explained greater kinesiophobia in patients reporting LOW physical activity.

3.3. High physical activity

TSK-17 demonstrated moderate correlations with crossover hop distance, single hop symmetry, and triple hop symmetry. TSK-17 demonstrated low correlations with IKDC, isokinetic extension torque, isokinetic extension power, extension MVIC torque, isokinetic flexion torque, isokinetic flexion work, isokinetic flexion power, flexion MVIC torque, isokinetic flexion torque symmetry, single hop distance, triple hop distance, and crossover hop symmetry. When entered into a multiple regression model, lesser triple

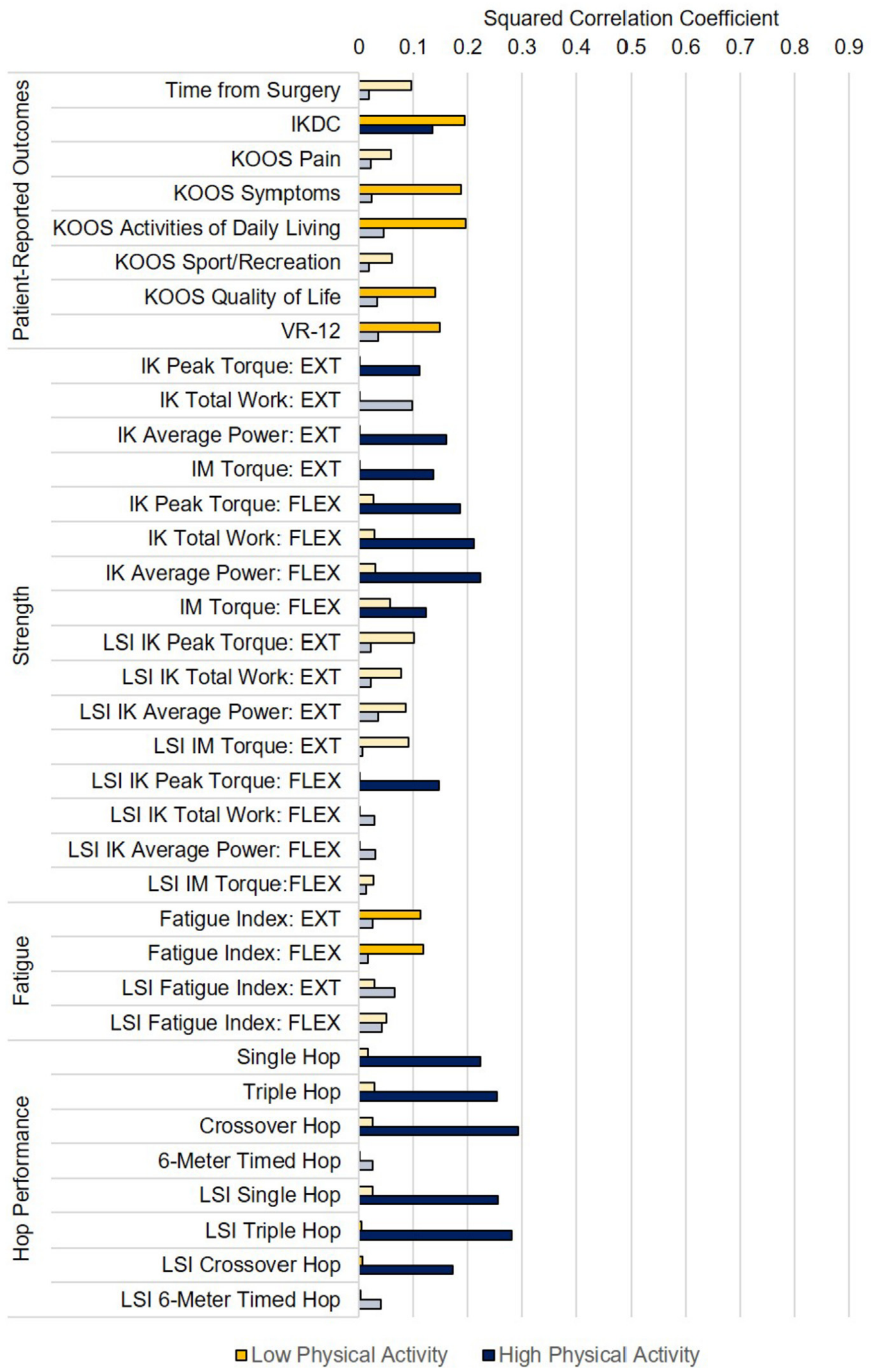

Fig. 1. Squared correlation coefficients between TSK-17 and all clinical outcome measures (patient-reported outcomes, strength, fatigue, and hop performance). Data are separated by patients who self-reported LOW (gold) and HIGH (navy) physical activity engagement. Solid bars indicate significantly correlated variables and shaded bars indicate non-significant findings. Abbreviations: IK, isokinetic; IM, isometric; EXT, extension; FLEX, flexion.

hop symmetry ($R^2 = 0.313$, $B = -23.755$, $P = .027$) and crossover hop distance ($R^2 = 0.081$, $B = -3.129$, $P = .047$), and IKDC ($R^2 = 0.135$, $B = -.191$, $P = .021$) explained greater kinesiophobia in patients reporting HIGH physical activity.

3.4. High vs. low physical activity

Less active patients reported greater kinesiophobia, lower physical activity, and lower global health compared to those who were more active (Table 1). Objective outcome measures did not statistically differ between patients in the HIGH and LOW physical activity groups (Table 4).

4. Discussion

In support of our hypothesis, the primary finding of our study was that TSK-17 was negatively associated with involved limb hamstrings strength (peak torque, total work, average power), single-leg hop performance (single, triple, crossover), and patient-reported function (physical activity, regional health, knee-related

Table 3
Regression models to explain variance in kinesiophobia among clinical outcome measures in patients reporting low and high physical activity levels after ACL reconstruction.

	Kinesiophobia (TSK-17)					
	B[b]	β[c]	R^2	Adjusted R^2	R^2 change	*P* value [d]
All Patients[a]						
Crossover hop distance	−3.237	-.331	.109	.097	.109	**.004**
KOOS activities of daily living	-.307	-.434	.189	.178	.189	< **.001**
Low Physical Activity[a]						
Knee flexion fatigue index	.201	.343	.118	.093	.118	**.038**
KOOS activities of daily living	-.307	-.547	.299	.279	.299	< **.001**
High Physical Activity[a]						
Triple hop LSI	−23.755	-.378	.313	.292	.313	**.027**
Crossover hop distance	−3.129	-.337	.394	.356	.081	**.047**
IKDC	-.191	-.367	.135	.112	.135	**.021**

Abbreviations: TSK, Tampa Scale of Kinesiophobia; KOOS, Knee Injury and Osteoarthritis Outcome Score; LSI, limb symmetry index; IKDC, International Knee Documentation Committee Subjective Knee Evaluation.
Statistically significant at $P \leq .05$.
[d] *P* values for individual explanatory variables.
[a] Objective and subjective variables were entered into separate regression models. Each list of variables represents the final regression model for objective and subjective data. Variables removed prior to entry due to multicollinearity: all patients (isokinetic flexion work, isokinetic flexion torque, single hop distance, triple hop distance), and high physical activity (isokinetic extension torque, isokinetic flexion torque, isokinetic flexion work, flexion MVIC torque, single hop distance, triple hop distance, single hop symmetry).
[b] Unstandardized beta coefficients.
[c] Standardized beta coefficients.

Table 4
Muscle strength, fatigue, and hop performance between patients reporting high and low physical activity after ACL reconstruction (mean ± SD).

	High Physical Activity (n = 39)		Low Physical Activity (n = 38)		*P* values	
	Involved Limb (mean ± SD)	Limb Symmetry Index (%)	Involved Limb (mean ± SD)	Limb Symmetry Index (%)	Involved Limb Comparison	Limb Symmetry Comparison
Isokinetic Knee Extension						
Peak Torque (Nm/kg)	1.63 ± 0.45	68.1 ± 15.6	1.61 ± 0.49	72.0 ± 19.0	.900	.338
Total Work (J/kg)	15.15 ± 4.46	74.7 ± 15.8	14.38 ± 4.79	73.3 ± 18.6	.472	.717
Average Power (W/kg)	1.63 ± 0.46	73.7 ± 16.3	1.56 ± 0.52	74.5 ± 18.7	.530	.844
Isometric Knee Extension						
Peak Torque (Nm/kg)	1.64 ± 0.59	68.6 ± 21.6	1.53 ± 0.60	67.7 ± 21.9	.437	.856
Isokinetic Knee Flexion						
Peak Torque (Nm/kg)	0.99 ± 0.29	96.6 ± 15.2	1.00 ± 0.33	100.1 ± 18.9	.811	.245
Total Work (J/kg)	8.98 ± 2.95	96.5 ± 20.9	8.93 ± 3.23	97.5 ± 21.3	.938	.844
Average Power (W/kg)	0.94 ± 0.32	95.0 ± 20.2	0.93 ± 0.33	98.5 ± 20.0	.909	.449
Isometric Knee Flexion						
Peak Torque (Nm/kg)	0.87 ± 0.31	99.5 ± 27.7	0.82 ± 0.28	90.7 ± 26.2	.493	.162
Fatigue Index						
Extension (%)	15.0 ± 10.1	82.9 ± 74.0	13.2 ± 12.5	64.7 ± 52.1	.495	.603
Flexion (%)	23.4 ± 9.6	99.8 ± 43.4	19.7 ± 10.3	81.8 ± 45.3	.106	.063
Hop Performance						
Single Hop	0.71 ± 0.21	88.8 ± 9.7[a]	0.67 ± 0.19	87.6 ± 13.2[a]	.626	.679
Triple Hop	2.50 ± 0.59	91.2 ± 8.4[a]	2.31 ± 0.59	91.2 ± 13.0[a]	.359	.488
Crossover Hop	2.32 ± 0.57	91.6 ± 8.9[a]	2.07 ± 0.60	91.3 ± 13.0[a]	.189	.495
Timed Hop (seconds/cm)	0.014 ± 0.005	109.1 ± 10.5[a]	0.013 ± 0.005	114.1 ± 49.5[a]	.178	.070

Statistically significant at $P \leq .05$.
[a] Compared using Mann-Whitney U tests.

symptoms, knee-related activities of daily living, knee-related quality of life, global health), suggesting that greater fear is related to worse clinical outcomes after ACLR. When analyzed in a multiple regression model among all patients, crossover hop distance was the only objective predictor of TSK-17. A similar relationship has been described in which patients reporting high fear were 7x more likely to have a single hop LSI less than 95% (Paterno et al., 2018). We observed the strongest relationship between TSK-17 and crossover hop distance, which may be attributed to the added complexity, or multiplanar component, of the task relative to a single hop. This finding appears to suggest that impaired crossover hop distance may be indicative of greater fear at the time of physician clearance, albeit, to a small degree (10.9%). Therefore, subjective ratings of fear appear to be warranted in combination with functional performance testing during the return-to-activity time frame.

The observed relationships between fear, lower extremity function, and patient-reported function were different when stratified by self-reported physical activity engagement. In less active patients, quadriceps and hamstrings fatigue were the only metrics of objective lower extremity function associated with TSK-17. However, when analyzed in a multiple regression model, hamstrings fatigue was the only objective predictor. This finding suggests that patients who are less active and have highly fatigable hamstrings, experience more fear. A previous study reported increased proximal tibial anterior shear forces, increased knee valgus moments, and decreased knee flexion angles in response to a general lower extremity fatiguing protocol during landing tasks after ACLR (Chappell et al., 2005). Therefore, it may be possible that patients with greater hamstrings fatigue perceive more knee instability during activities of daily living, thus contributing to the perception of fear. In support of this theory, the $KOOS_{ADL}$ was the only subjective predictor of TSK-17 in less active patients, and explained greater variance than did hamstrings fatigue (29.9% vs. 11.8%).

Interestingly, fear was more related to patient-reported function (IKDC, $KOOS_{symptoms}$, $KOOS_{ADL}$, $KOOS_{QOL}$, VR-12), rather than objective measures of lower extremity function, such as strength and hop performance, in less active patients. Although the strength of associations were low, this may reflect a lack of exposure to dynamic physical activities among these patients. That is, if patients have not attempted to participate in physically demanding tasks, they may have an unpredictable (heterogeneous) fear-related response when performed during our study. For example, patients who had not performed hopping tasks prior to participation in our study could have had a larger or smaller fear response from not knowing how well they would be able to perform the task, yet this was not uniform. An unpredictable fear response appears to be supported by the larger variability in TSK-17 observed among less active patients. According to the relationships observed, it is feasible that the fear experienced by less active patients may have been influenced by their perceptions of disability related to knee function and global health more so than traditional measures of objective lower extremity function. Therefore, targeting improvements in subjective ratings of function earlier in the rehabilitation process may be most appropriate to minimize the impact of fear in less active patients. This may simply call for a more routine serial measurement of regional and psychological functioning during early rehabilitation phases. It is possible that the common practice of waiting to quantify such impairments until the time of return-to-activity is preventing adequate, or timely, resolution.

Fear was most related to single-leg hop performance and muscle strength (hamstrings > quadriceps) in more active patients. In contrast to their less active counterparts, this finding may be a byproduct of greater risk exposure and perception. It is possible that patients gain a better perception of their physical function as they become more active. For example, patients may not recognize limitations until encountering tasks difficult enough to challenge their physical abilities, thus disassociating fear from physical activity if less active. Further, when clinically meaningful impairments related to strength and functional performance persist as physical activity increases, patients' perception of fear may become closely associated with such tasks. When analyzed in a multiple regression model, triple hop symmetry and crossover hop distance were the only objective predictors of TSK-17. These findings suggest that patients who are more active, but have muscle weakness and poor hop performance, experience greater fear.

In addition to our objective findings, TSK-17 was only associated with subjective knee function (IKDC) among more active patients, yet to a lesser degree than hop performance (13.5% vs. 35.6%). This may reflect the more active lifestyles of this patient group in comparison to the relationship observed between simple activities of daily living and fear in less active patients. Although we would intuitively expect fear to be related to additional metrics of subjective function, we did not observe such relationships in more active patients. As such, improvements in hop performance and muscle strength appear to be more appropriate clinical targets to minimize fear in more active patients, albeit caution should be applied as these factors demonstrated low-to moderate correlations. However, it is possible for patients to be highly active, yet report high fear, potentially leading to greater risk for a second injury. In our cohort, 17.9% ($n = 7/39$) of more active patients reported a TSK-17 score consistent with high fear (Vlaeyen et al., 1995), compared to 31.6% ($n = 12/38$) less active patients. Therefore, addressing hop performance, muscle weakness, and the ability to perform knee-related sport activities should be considered when managing the highly active patient with high fear.

Consistent with our hypothesis, measures of lower extremity function were more associated with fear among patients who were more active, and measures of patient-reported function were more associated with fear in those who were less active. It should be noted that the patient-reported outcomes we used assess a continuum of function from basic activities of daily living to dynamic sport-specific tasks, such as jumping and landing. Therefore, the specific activities reflected in each questionnaire should be considered important relative to kinesiophobia, more so than the subjective nature of the assessment. Regardless of physical activity engagement, IKDC was associated with TSK-17, which agrees with previous reports (Chmielewski et al., 2008, 2011; Hartigan, Lynch, Logerstedt, Chmielewski, & Snyder-Mackler, 2013) that greater fear is related to lesser subjective knee function. This may be due to the fact that the IKDC asks questions that range from rising from a chair to stopping and starting quickly. In our study, less active patients also reported greater fear and lesser global health compared to those who were more active. As an example, the combination of low physical activity engagement, high fear, and poor global health perception at the time of physician clearance is particularly concerning to the patient returning to a physically active lifestyle. Although a causal relationship between these factors cannot be elucidated from our findings due to the cross-sectional nature of this study, these data appear to support delayed clearance and inclusion of psychological-based rehabilitation strategies as previously advocated for (Ardern, 2015; Coronado et al., 2018; Everhart et al., 2015; Grindem, Snyder-Mackler, Moksnes, Engebretsen, & Risberg, 2016). Unfortunately, the current base of evidence on such strategies is limited and inconsistent.

Clinical outcomes have recently been compared between patients with high and low fear (Paterno et al., 2018). Patients with high fear have been reported to have an increased likelihood of lower physical activity (Lentz et al., 2015), asymmetric quadriceps strength, and asymmetric hop performance at the time of return-to-sport (Paterno et al., 2018). In contrast, we compared patients based on self-reported physical activity engagement, rather than by level of fear. In our study, physical activity differed between groups, supporting our stratification technique. Our approach resulted in Godin scores above (98.2) and below (46.6) previously published data (Norte et al., 2018a, 2018b) from a comparable population ($ACLR = 59.1$ vs. $control = 75.5$), supporting the description of high and low physical activity among our sample. Although TSK-17 differed between groups, the effect was moderate (Cohen's d effect size: -0.52 [-0.97, -0.06]), which may partially explain the similarities in lower extremity function observed. Additionally, global health ratings were lower in less active patients. Reduced global health has been reported in patients 6–24 months after ACLR compared to healthy controls (Norte et al., 2018a, 2018b), and associated with a lower physical activity level. More recently, greater disablement and decreased health related quality of life have been reported at an average of 4 years after ACLR, suggesting this is not only a problem during early recovery (Hoch, Sinnott, Robinson, Perkins, & Hartman, 2018). Similar to our findings, a previous study (Werner et al., 2018) identified deficits in subjective knee function despite no differences in physical function among patients who did not return to sport after ACLR compared to those who did. These data appear to support the need for a multi-faceted evaluation, as well as a link between physical activity, global health, and fear.

We used the Godin Leisure-Time Exercise Questionnaire to measure self-reported physical activity engagement, as it attempts to capture leisure-time activity during a typical 7-day period, rather than a single point in time, and encompasses a spectrum of mild-to-strenuous exercise. While mean scores differed among patients in each physical activity group, a lack of recommended values may limit the interpretation of our findings. Additionally, previous studies (Bell et al., 2017; Kuenze et al., 2017) have reported no relationship between objective and self-reported physical activity (Tegner and Marx activity scales) in patients after ACLR. Therefore, future studies are warranted to investigate the relationship between fear and objective measures of physical activity.

4.1. Study limitations

We used kinesiophobia as the primary outcome in our study, yet, fear only represents a single psychological construct, and should not be interpreted as a comprehensive assessment of the psychological and psychosocial impact of ACLR. Factors such as psychological readiness, locus of control, self-confidence, optimism, self-motivation, stress, social support, and self-identify have been reported to influence clinical outcomes after ACLR (Ardern et al., 2013b; Burland et al., 2018; Christino, Fantry, & Vopat, 2015; Everhart et al., 2015; Lentz et al., 2015), and warrant further investigation.

Our sample of patients reported relatively low fear, with a mean score of 32.8 (range: 20–49), and 24.6% (n = 19/77) classified as high fear. However, this was similar to previous studies (Ardern et al., 2013b, 2015) that assessed kinesiophobia 4–12 months after ACLR using the TSK-17, which reported values ranging 33.0–35.6 among those who returned to preinjury activity, and 34.0–37.0 among those who did not return. Therefore, we felt that our sample was representative of patients wishing to return to physically active lifestyles after physician clearance.

Future work is warranted to determine the most appropriate cutoff value for Godin scores when using the weighted sum method. Previous authors have described a revised classification system that omits mild exercise, however the applicability of this method to a younger cohort remains uncertain.

Lastly, post-operative rehabilitation was performed according to standard practices, but could not be standardized across patients, and any exposure to psychologically information rehabilitation protocols was not documented. Although the prescribed protocols within our University health care system were similar, patients were not restricted to complete rehabilitation in our clinic, and could have received additional care from another health care provider. It is unclear if variations in post-operative care influenced our findings.

5. Conclusions

Greater kinesiophobia was associated with worse hamstrings strength, single-leg hop performance, and patient-reported function after ACLR. Relationships differed when stratified by self-reported physical activity engagement. Interventions that improve the ability to perform knee-related activities of daily living may be most appropriate to minimize the impact of fear in less active patients, while those which improve hop performance and the ability to perform knee-related sport activities may be better suited for more active patients. The cause and effect relationships between fear and clinical outcomes remain an area for future clinical trials after ACLR.

Conflicts of interest

None declared.

Ethical approval

The University Biomedical Institutional Review Board has approved the work described in this manuscript. All participants provided written and verbal informed consent prior to participation.

Funding

None declared.

Acknowledgements

None declared.

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