Original Research

Adolescents Are Less Physically Active Than Adults After Anterior Cruciate Ligament Reconstruction

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Background: Sources of physical activity (PA) and motivation for return to sport after anterior cruciate ligament reconstruction (ACLR) differ between adolescents and adults. It is unclear whether these differences influence participation in PA during the first year after ACLR when individuals are transitioning from rehabilitative care to unrestricted activity.

Purpose: To compare device-assessed measures of PA between adolescents and adults at 6 to 12 months after ACLR.

Study Design: Cross-sectional study; Level of evidence, 3.

Methods: Included were 22 adolescents (age, 15.9 ± 1.2 years; time since surgery = 8.0 ± 2.1 months) and 23 adults (age, 22.5 ± 5.0 years; time since surgery = 8.2 ± 2.1 months) who were cleared for unrestricted PA after primary unilateral ACLR. Participants were considered physically active if they met their age-specific United States Department of Health and Human Services PA guidelines. Participants wore an accelerometer-based PA monitor for at least 7 days. Daily minutes of moderate to vigorous–PA (MVPA) and daily step counts were reported and compared between age groups using analysis of covariance, with monitor wear time and sex included as covariates. The association between age group and meeting age-specific PA guidelines was assessed using binary logistic regression and reported as an odds ratio.

Results: Adults with ACLR participated in 16 minutes more MVPA per day (49 ± 22 vs 33 ± 16 minutes per day; $P < .001$) and took 2212 more steps per day (8365 ± 2294 vs 6153 ± 1765 steps per day; $P < .001$) when compared with adolescent participants. In addition, 83% of adults were physically active, compared with 9% of adolescents (odds ratio = 60.2; 95% CI, 7.6-493.4).

Conclusion: Adolescents with ACLR were less physically active than adults with ACLR, and only 9% of adolescents met aerobic PA guidelines. This is concerning because PA patterns adopted early in life are predictive of PA patterns in adulthood. Our findings indicate a need to better understand underlying causes of reduced PA among adolescents with ACLR and to develop intervention strategies that promote engagement in adequate PA after rehabilitation.

Keywords: accelerometer; moderate to vigorous–physical activity; return to sport; step counts

The rate of anterior cruciate ligament reconstruction (ACLR) has increased over 60% in the past 20 years.[26] During this time, individuals younger than 20 years have experienced the highest rate of increase in total number of ACLR procedures.[16,26] This is particularly concerning because ACLR has been linked with decreased health-related quality of life,[19] decreased participation in sport,[3,4] and increased risk of chronic diseases such as osteoarthritis.[25] While the links between ACLR and participation in physical activity (PA) have been preliminarily described among adult patients,[7,8,18,22,23,36] significantly more work is needed to understand how adolescents (age <18 years) and adults differ as regards PA participation post-ACLR. This is essential because reducing participation in PA at an early age, when risk of ACL injury resulting in ACLR is greatest, could negatively influence PA across patients' life span.[12,20,35] One of the most common goals of ACLR is to return to sport-related activity, but ACLR may serve as a catalyst that shifts a population that previously exhibited healthy PA behavior to a physically inactive lifestyle. Patients are most likely to be cleared for unrestricted sport and PA between 6 and 12 months after ACLR, which marks an important time of transition in readopting a physically active lifestyle during ACLR recovery. Based on the consistent increases in ACLR among adolescents and the potential risks associated with reduced PA participation early in the life span, there is a

The Orthopaedic Journal of Sports Medicine, 10(2), 23259671221075658
DOI: 10.1177/23259671221075658

need to better understand whether ACLR is a barrier to PA among young, otherwise healthy individuals.

Return to preinjury levels of sports participation is among the most commonly discussed clinical goals for patients recovering from ACLR.[2,11,19,36] Accordingly, return to sport is commonly reported as a primary indicator of successful rehabilitation after ACLR and as a surrogate for participation in PA.[3,4] However, when return to sport is used as a primary indicator of PA participation after ACLR, it does not take into account the goals of patients that may not include a desire to return to sport.[42] Further, using return to sport does not consider that the source of PA may differ between adolescent patients who are engaged in organized sports and adults who are more likely to engage in less structured or non-sport-based recreational PA.[14] Additionally, national recommendations for adequate frequency, duration, or intensity of PA differ between adolescents and adults[32] and should be recommended accordingly to promote adequate PA participation.[21] In recent studies, adults (age $\geq$18 years) with a history of ACLR participate in approximately 110 fewer weekly minutes of moderate to vigorous–PA (MVPA) and have 2.4 times worse odds of meeting age-specific aerobic PA guidelines when compared with individuals without a history of injury.[8,22] While studies of PA in non-ACL-injured populations indicate that there are meaningful changes in PA participation during the transition from adolescence to early adulthood,[35] it remains unclear whether age plays a meaningful role in determining post-ACLR participation in PA.

Given that the typical sources of PA,[14] motivation for return to sport,[1] and recommended characteristics of PA required to be physically active differ between adolescents and adults,[32] it is important that we understand how age affects device-assessed PA participation following clearance for unrestricted PA after ACLR. Therefore, the purpose of this study was to compare device-assessed measures of PA (ie, average daily step counts and daily minutes spent in MVPA) between adolescents and adults 6 to 12 months post-ACLR. We hypothesized that adolescents with ACLR would take a greater number of daily steps and participate in more daily MVPA as compared with adults with ACLR because healthy adolescents have been shown more active than healthy adults.[37] Our secondary purpose was to characterize the odds of meeting age-specific PA recommendations between adolescents and adults after ACLR. We hypothesized that adolescents with ACLR would have significantly greater odds of meeting age-specific PA recommendations as compared with adults with ACLR.

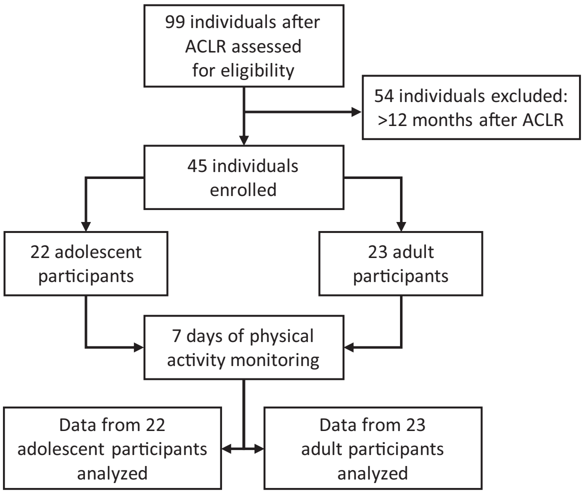

Figure 1. Consort flowchart for the current study. ACLR, anterior cruciate ligament reconstruction.

METHODS

This multisite, cross-sectional study received institutional review board approval, and all participants provided written informed consent before participating in the study.

Participants

A total of 99 ACLR patients were screened, and 45 participants were enrolled from the campus communities and clinical populations of 2 universities in the Midwest region of the United States (Figure 1). The initial 99 participants were involved in ongoing research studies in the 2 laboratories and were therefore considered for involvement in the study described in the current study. Participants were included in this study if they were 13 to 35 years of age; had primary, unilateral ACLR 6 to 12 months before study enrollment; reported that they had been cleared for unrestricted activity; and did not report a health concern that would limit their ability to engage in recreational PA. The upper age limit of 35 years was selected to minimize the likelihood that participants in the adult group were

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Final revision submitted November 8, 2021; accepted November 12, 2021.
One or more of the authors has declared the following potential conflict of interest or source of funding: This work was partially funded by a grant from the National Athletic Trainers' Association Research and Education Foundation (award 1718NIP01). L.W. has received education payments from Arthrex. AOSSM checks author disclosures against the Open Payments Database (OPD). AOSSM has not conducted an independent investigation on the OPD and disclaims any liability or responsibility relating thereto.
Ethical approval for this study was obtained from Michigan State University (ref No. 17-1372).

experiencing symptomatic knee osteoarthritis at the time of enrollment and to align our sample with recommendations for osteoarthritis prevention studies, including individuals with knee injury.[24,41]

Participants were categorized as adolescents (<18-years old) or adults (≥18-years old) based on their age at the time of study enrollment.

Patient-Reported Outcome Measures

Participants completed the Tegner Activity Scale (TAS) immediately after enrollment to determine the subjective peak level of activity at the time of enrollment. The TAS is a valid and reliable survey in individuals with a history of ACLR, consisting of an 11-point Likert scale.[9] A score of 0 indicates that participants are unable to participate in any sport or recreational activity due to disability, and a score of 10 indicates that participants compete in professional or collegiate levels of sport on a regular basis. A score of 1 point on the TAS is considered the minimal detectable difference between groups.[9] Participants also completed the Knee injury and Osteoarthritis Outcome Score (KOOS), which is a valid and reliable assessment of pain, symptoms, function, and knee-related quality of life.[13]

TABLE 1
Accelerometer Data Collection and Analysis Methods[a]

Item to Report	Method
Model of accelerometer	ActiGraph wGT3X-BT and GT9X Link
Data collection sampling rate	30 Hz
Data analysis epoch length	Adults: 60-second epoch Adolescents: 15-second epoch
Placement of accelerometer	Anterior axillary line, right hip
Accelerometer distribution method	In-person and via mail
Days of data collection	≥7 days
Criteria for defining nonwear of accelerometer	Minimum length: 90 minutes Small-window length: 30 minutes Spike tolerance: 2 minutes
Number of valid days and number of minutes per day of accelerometer data needed to be included in analysis	≥4 days (3 weekend days, 1 weekend) 600 minutes per day
Accelerometer data PA outcome of interest and interpretation method	Minutes per day of MVPA Minutes per week of MVPA Mean daily step count

[a]Based on recommendations of accelerometry reporting methods. MVPA, moderate to vigorous–physical activity; PA, physical activity.

Device-Based PA Assessment

Participants were instructed to wear an ActiGraph wGT3X-BT or GT9X Link monitor (ActiGraph) on an elastic belt over their right hip for at least 7 days. Prior studies have reported good agreement between triaxial and uniaxial counts of the 2 monitors.[29] Participants were asked to wear the monitor during all waking hours except for during water-based activities (eg, swimming or showering). It should be acknowledged that this approach to PA assessment does not capture swimming and may not capture periods of stationary weight training, both of which are commonly recommended for patients recovering from ACLR. An investigator maintained communication with participants via phone, email, or in-person conversation to promote compliance, proper use, and adequate charge of the activity monitor. The ActiGraph monitors collected data in raw acquisition mode, after which the data were processed and analyzed using ActiLife software (ActiGraph).

Monitor wear time was estimated and validated using the Choi algorithm.[10] This algorithm uses the count and frequency triaxial accelerations to discriminate between periods of wear and nonwear.[10] A participant's data were considered valid if monitor wear time exceeded at least 600 minutes over at least 3 weekdays and 1 weekend day.[40] Only participants with valid data were included in the analysis. Relevant data collection and analysis methodology, in compliance with guidelines recommended by Montoye et al,[28] is reported in Table 1.

PA Data Processing

Light, moderate, and vigorous PA were categorized using the number of vertical-axis activity counts that occurred during periods of wear time and based on the age-specific cut point recommendations of Troiano et al[37] and Evenson et al[17] for adults and adolescents, respectively (Table 2). Data were processed in 60-second epochs for adults and 15-second epochs for adolescents, based on recommendations from Migueles et al.[27] We opted to use age-specific PA cut-off points because adolescents demonstrate a higher resting energy expenditure compared with adults, meaning that fewer activity count unit times result in greater metabolic expenditure.[38] These cut-off points were selected

TABLE 2
Activity Intensity Cut-Off Points Commonly Applied to Data Captured Using Research-Grade Triaxial Accelerometry

		Activity Intensity, cpm[a]			
Study (Year)	Population	Sedentary	Light	Moderate	Vigorous
Troiano et al (2008)[37]	Adult	0-99	100-2019	2020-5998	5999+
Evenson et al (2008)[17]	Adolescent	0-99	100-2295	2296-4011	4012+

[a]cpm, activity counts per minute.

because they have been widely used in PA and sports medicine literature,[27] and both rely on vertical-axis acceleration data for characterization of activity intensity.[17,37] Based on these cut-off points, the total active time spent in moderate and vigorous intensity activity was summed, and the daily and weekly number of minutes of MVPA were reported. Mean daily step counts were also measured during the PA monitoring period. In brief, the proprietary step count algorithm provided by the ActiLife software was applied to the vertical-acceleration data during valid wear. The mean for each day of valid step count data was then calculated for each participant, and mean daily step counts were then reported.

Aerobic PA Guidelines

We categorized adults and adolescents as meeting age-specific aerobic PA thresholds using the 2018 United States Department of Health and Human Services (USDHHS) guidelines.[32] It is recommended that adults participate in at least 150 minutes of MVPA or 75 to 150 minutes of vigorous activity weekly. The recommendation for adolescents is at least 60 minutes per day of MVPA, with at least 3 of those days including vigorous PA. Based on these recommendations, we classified participants in our study as physically active if they met their age-specific PA guideline and not physically active if they did not.

Statistical Analysis

Participant age, height, weight, months since surgery, total PA monitor wear time, and KOOS subscale scores were compared between age groups using independent-samples *t* tests. Participant sex was compared between groups using the Fisher exact test, and graft-source frequencies were compared between groups using a chi-square test. Preinjury and current Tegner activity levels were compared between groups using a Mann-Whitney *U* test as data obtained from this scale are noncontinuous. Mean daily minutes in MVPA, weekly minutes in MVPA, and daily steps were compared between adolescent and adult participants using analysis of covariance with total monitor wear time and participant sex included as covariates. We also evaluated the association between minutes per day of MVPA and data-collection site, using binary logistic regression, and compared median month of data collection between age groups using a Mann-Whitney *U* test to determine whether these variables should be included in our models as covariates. The association between participant age group and meeting age-specific aerobic PA guidelines was assessed using binary logistic regression, and the findings were reported using an odds ratio and 95% CI. An a priori alpha level was established as $P < .05$. All statistical analyses and data visualizations were completed in jamovi Version 1.6.15.[33]

We estimated the sample size needed to detect a significant between group difference based on the work of Bell et al, who reported a large difference in daily minutes of MVPA (Cohen $d = -0.72$) and daily steps (Cohen $d = -1.21$) between healthy adults and adults with ACLR.[8] While our study is a comparison between age groups of individuals with ACLR, we felt that the healthy adult group in the Bell study would be a reasonable representation of our hypothesized PA participation among adolescents with ACLR. Therefore, given the magnitude of between-group differences in the previous study and the design of the current study, we estimated that 46 participants would be needed to detect between-group differences.

RESULTS

Participant demographics, patient-reported outcome measures, and PA outcomes are summarized and compared between groups in Table 3.

Adult participants reported worse function in sport and recreation ($P = .006$), better knee-related quality of life ($P < .001$), and lower current Tegner activity levels when compared with adolescent participants ($P = .004$). On average, adults participated in 16 more minutes of MVPA per day ($P = 0.02$) and took 2212 more steps per day ($P < .001$) when compared with adolescent participants after controlling for PA monitor wear time and participant sex (Figure 2). Data collection site was not significantly associated with average daily minutes of MVPA ($R^2 = 0.04$) or daily step counts ($R^2 = 0.06$), and the month of data collection did not differ between age groups (adult median = 5.7; adolescent median = 6.2; $U = 242$; $P = .81$). Therefore, we did not include data collection site or month of data collection as covariates in these analyses.

When daily or weekly MVPA was compared with USDHHS PA guidelines, 83% of adults were considered physically active, while only 9% of adolescents were physically active after controlling for sex and PA monitor wear time (odds ratio = 60.2; 95% CI, 7.6-493.4) (Table 4).

DISCUSSION

Our findings indicate that adolescents 6 to 12 months post-ACLR participate in 33% less daily MVPA and take 26% fewer steps per day when compared with adults, despite reporting a higher Tegner activity level at the time of PA assessment (Table 3). As a result, 83% of adults were considered physically active, while only 9% of adolescents were considered physically active (Table 4). These findings were the opposite of our hypotheses, and the magnitude of differences between age groups was considerably larger than anticipated. Consequently, our findings indicate a need to better understand underlying causes of reduced PA among adolescent individuals with ACLR to develop and implement intervention strategies to promote engagement in adequate PA following the completion of structured rehabilitation.

Sports participation is the primary source of PA for adolescent Americans, and return to sport(s) is the most consistently reported goal for adolescent patients after ACLR.[31] However, this study found that 6 to 12 months after ACLR, adolescent patients who had been cleared for unrestricted PA participated in only 25 minutes per day of

TABLE 3
Participant Demographics, Patient-Reported Outcome Measures, and PA Outcomes[a]

	Adolescent (N = 22)	Adult (N = 23)	*P*
Sex, male:female, n	15:7	9:14	.05
Age, y	15.9 ± 1.2	22.5 ± 5.0	**<.001**
Height (m)	1.7 ± 1.2	1.7 ± 1.3	.43
Weight (kg)	71.6 ± 19.7	76.6 ± 20.3	.41
Time since surgery (mo)	8.0 ± 2.1	8.2 ± 2.1	.73
Graft source, n	9 BTB, 13 HS, 0 AG	8 BTB, 14 HS, 1 AG	.58
Tegner activity level, full range			
Preinjury	9 [7-10]	9 [6-10]	0.06
Current	7 [5-10]	6 [3-9]	**0.004**
KOOS subscale			
Symptoms	66.4 ± 7.1	70.2 ± 18.5	0.37
Pain	94.2 ± 8.6	91.1 ± 8.1	0.22
Function in daily living	98.5 ± 5.6	94.8 ± 6.7	0.06
Sport/Rec	90.0 ± 11.6	78.3 ± 15.6	**0.006**
Quality of life	77.3 ± 17.3	60.6 ± 13.4	**<0.001**
Monitor wear time (minutes)	5447 ± 1405	5077 ± 1058	0.97
MVPA[b]			
Minutes per day	33 ± 16	49 ± 22	**0.02**
Minutes per week	234 ± 113	341 ± 153	**0.02**
Steps per day[b]	6153 ± 1765	8365 ± 2294	**<0.001**

[a]Data are presented as mean ± SD unless otherwise indicated. Boldface *P* values indicate statistically significant difference between groups ($P < .05$). BTB, bone patellar tendon bone–autograft, HS, hamstring tendon autograft; AG, allograft; IQR, interquartile range; MVPA, moderate to vigorous–physical activity; Sport/Rec, function in sports and recreation.
[b]Total physical activity monitor wear time and participant sex were covariates.

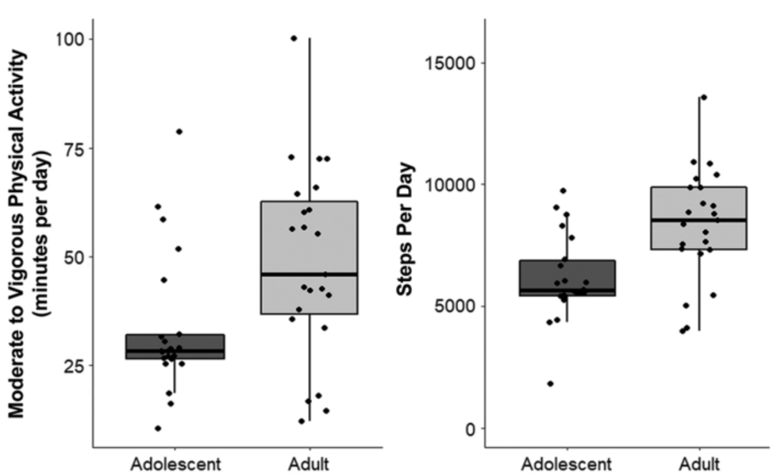

Figure 2. Adult participants with ACLR engaged in more daily MVPA ($P = .02$) and took more steps per day ($P < .001$) compared with adolescent participants with ACLR after accounting for participant sex and PA monitor wear time (minutes). ACLR, anterior cruciate ligament reconstruction; MVPA, moderate to vigorous–physical activity.

MVPA as compared with 49 minutes per day among our adult participants at a similar time post-ACLR (Figure 2). To our knowledge, this is the first study to investigate the role of participant age in PA participation after ACLR. Our findings are contrary to our hypotheses and the broader literature about PA participation patterns in healthy adolescents and adults. In the general population, healthy young adults tend to participate in fewer minutes of MVPA as compared with healthy adolescents.[6] Also, healthy adolescents experience a negative MVPA trajectory from age 9 through the end of adolescence.[14] This decline in PA tends to align with reduced opportunity for participation in organized sports as well as changes in social roles (eg, gaining employment, graduating from high school) that distract from consistent engagement in PA during the transition to adulthood.[14] In our study, it appears that at an average

TABLE 4
Odds of Participants Achieving Age-Specific Physical Activity Guidelines After ACLR[a]

	Adults	Adolescents	Odds Ratio (95% CI)[b]
Physically active	19 (82.6%)	2 (9.1%)	60.2 (7.6-493.4)
Not physically active	4 (17.4%)	20 (90.9%)	

[a]ACLR, anterior cruciate ligament reconstruction.
[b]Odds ratios were calculated using binary logistic regression while accounting for participant sex and monitor wear time.

of 8 months post-ACLR, adolescent participants are experiencing significant barriers to PA participation that may not be present for adults during the same phase of recovery. In a recent qualitative study investigating barriers to recovery and re-engagement in PA, adolescent individuals with ACLR (time since surgery = 28-149 days) reported significant concerns about maintenance of their role on their organized sports team following their lengthy rehabilitation process and fear of injury that limited enthusiasm about re-engaging in sport.[15] Future studies should determine whether underlying psychosocial, environmental, or physical barriers to PA are associated with adolescents meeting age-specific PA guidelines to better understand the sources and potential solutions to this important clinical problem.

Re-engagement in sport is a reasonable goal for patients with ACLR who participated in sport before injury. However, our findings indicate that re-engaging in sport after ACLR does not necessarily ensure that these patients will reap the benefits of participation in adequate daily or weekly MVPA. This is concerning, as achieving age-specific PA guidelines results in well-established benefits for cardiovascular health, physical function, and health-related quality of life.[32] For example, the adolescent participants included in this study reported a median current Tegner activity level of 7 (full range, 5-10), indicating that they were participating in some form of recreational or competitive sport at the time of study participation. Additionally, adolescent patients reported KOOS–sport/recreation scores that exceed the patient-acceptable symptom state for the subscale, indicating that they were feeling well during sport and recreational activities.[30] Despite this, only 9% of adolescent participants in the current study met the current PA guidelines for adolescents (ie, >60 minutes per day of MVPA). This percentage among adolescents is considerably less than a cohort of young female athletes (aged 14.9-22.6 years) who were 1 to 2 years post-ACLR (46.0% met aerobic PA guidelines) included in a recent study.[18] Conversely, 82.6% of adults included in our study participated in at least 150 minutes of MVPA per week, which is a much larger proportion than previous reported in a cohort of individuals 1 to 5 years post-ACLR (39.2% of adults met aerobic PA guidelines).[22] This is despite the fact that nearly 20% of adult participants in the current study reported that they were not consistently participating in organized or recreational sport (Tegner level ≤4). The design of our study limits our ability to understand the underlying cause of the disparity in meeting age-specific aerobic PA guidelines between adults and adolescents with ACLR. However, it appears that adults with ACLR have adopted patterns of PA participation independent of return to preinjury level of sport participation, resulting in the ability to more consistently engage in MVPA.[34] Adolescents should be encouraged to return to sport if they desire to do so. However, assisting young patients in developing an understanding of the importance of PA as well as sources of PA that are not reliant on participating in organized sport (eg, recreational running or interval training) may help develop patterns of PA participation that can be sustained, regardless of return-to-sport status.

In addition to comparing MVPA between adults and adolescents with ACLR, we also compared the average daily step counts between age groups because (1) step counts are a more feasible metric for self-monitoring due to the availability of commercial activity monitors and (2) daily step counts are associated with knee joint health after ACL injury.[43] Previous work has shown that adults with ACLR take approximately 1100 fewer steps per day as compared with healthy controls[8,23] and that reduced step counts are associated with poorer knee self-efficacy and quality of life after ACLR.[7] To our knowledge, this is the first study to quantify average daily step counts in adolescents with ACLR. Similar to our MVPA findings, adolescent participants took 2116 fewer steps per day than adult participants and their average daily step counts were only 63% of the 10,000 steps per day that were recommended as a minimal acceptable value for adolescents to maintain a healthy lifestyle by Tudor-Locke et al.[39] While walking may not be the most desirable form of exercise for adolescents with ACLR, integration of daily step promotion during rehabilitation may be a feasible goal toward normalizing joint loading and enhancing PA participation in this patient population, regardless of return-to-sport status.

Limitations

Our study was cross-sectional, which significantly limited our ability to make inferences about the trajectory of PA participation among adolescents and adults over the course of their recovery from ACLR, including changes in PA participation before ACLR. While we did capture PA outcomes at an important transition from PA limitations during structured rehabilitation to unrestricted PA participation, the results observed in this study should not be extrapolated beyond this time point. In addition, this design limited our ability to characterize preinjury activity level to the use the TAS at the time of study enrollment, which may have introduced meaningful recall bias. Additionally, the timeline and criteria used for clearance for unrestricted activity may have significantly varied between participants because participants were recruited and enrolled from clinical populations at 2 different universities as well as the local communities in midsized, Midwestern cities. Future investigations should document the criteria utilized for clearance and consider diversifying the geographical locations of data collection sites to enhance the generalizability of the findings.

Further, we did not investigate the rationale for diminished PA or the barriers to PA participation among our sample. Recent studies have indicated that adults and adolescents have meaningfully different perceptions of their rehabilitation experience and report disparate PA goals following clearance for unrestricted activity. Moreover, individuals who are in secondary school engage in different types of PA when compared with older individuals no longer in secondary school.[5,42] While our study is the first to directly compare PA among these age groups, future investigations should focus on developing greater understanding regarding the underlying cause of PA participation limitations, in addition to quantifying PA among this patient population. Lastly, the distribution of sexes was significantly different between our groups, which may have influenced our findings. While participant sex was included as a covariate in our primary analyses, previous studies have reported differences in MVPA between adult men and women with ACLR.[22] Future studies should consider investigating sex differences in PA among adolescents with ACLR.

CONCLUSION

Our results indicate that adults participate in nearly 33% more weekly MVPA and take 26% more steps per day when compared with adolescent individuals who have been cleared for unrestricted PA 6 to 12 months after ACLR. In addition, 83% of adults were considered physically active, while only 9% of adolescents were considered physically active in this study. These findings are concerning, as PA participation patterns adopted early in life are predictive of PA engagement during adulthood. While many of the adolescent participants included in this study indicated that they had made a return to some level of sport participation, it does not appear that such participation was of sufficient duration or intensity to meet current PA guidelines.

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